SEP 17 1923

Subscription Price:
United States and Canada, $6.00 Per Year.
Great Britain, 25 Shillings; Single Copies, 3 Shillings.
Foreign, $6.00 Per Year; Single Copies, 75 Cents.

VOLUME V SEPTEMBER, 1923 NUMBER 5

THE JOURNAL OF INDUSTRIAL HYGIENE

AND ABSTRACT OF THE LITERATURE

OFFICIAL ORGAN OF
THE AMERICAN ASSOCIATION OF INDUSTRIAL PHYSICIANS AND SURGEONS

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Studies on Undernourishment in Industry. II

Lead Studies: VI. Absorption of Lead by the Upper Respiratory Passages

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Atmospheric Particulate Matter: II. The Use of Electric Precipitation for Quantitative Determinations and Microscopy

PUBLISHED MONTHLY BY HARVARD MEDICAL SCHOOL
EDITORIAL AND BUSINESS OFFICES : : 240 LONGWOOD AVENUE, BOSTON 17, MASSACHUSETTS
GREAT BRITAIN : : INDUSTRIAL WELFARE SOCIETY, 51 PALACE STREET, WESTMINSTER, S. W. 1

Entered as second-class matter, at the Post Office at Boston, Mass., under Act of March 3, 1879. Published Monthly.
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THE JOURNAL OF INDUSTRIAL HYGIENE

PUBLISHED MONTHLY

VOLUME V SEPTEMBER, 1923 NUMBER 5

STUDIES ON UNDERNOURISHMENT IN INDUSTRY. II.*

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THERE are a few new developments and some additional data, confirmatory of the impressions recorded in the first report on undernourishment in industry (THIS JOUR., 1922-1923, *4*, 93), which seem to us to warrant the publication of this second report.

PHYSICAL SIGNS OF UNDERNOURISHMENT

That there is a distinct difference between undernourishment and underweight becomes more apparent the longer one observes individuals from the standpoint of nutrition. As there is no definite agreement on the question as to what constitutes undernourishment, we shall hazard a definition, which although probably not complete, nevertheless establishes a satisfactory standard for purposes of this study. Our definition is this: Undernourishment is that physical state evidenced by,

(a) Underweight (according to the standing height, age, and weight table).

(b) Anemia.

(c) Flabby musculature.

(d) Relaxed skin.

(e) Poor sustained response to mental and physical effort.

This is the picture presented by the convalescent typhoid, an underfed prisoner of war, or the patient with pyloric block, all of whom represent the extreme of undernourishment. Undernourished to a lesser degree, but quite definitely so, many workers are trying to "carry on" in competition with their healthy fellows.

Criticism of the explanation following the word *underweight* is accepted. There is a question as to which is the best nutritional standard. We have tried all of the more generally used methods. The sitting height, bust measure, and weight ratio is not satisfactory as applied to working women, because of the variation in the amount of breast tissue and the difficulty in obtaining accurate measurements. We should consider von Pirquet's system the most

*Received for publication July 12, 1923.

exact if tables of experience representing the study of adults in this country, rather than in Austria, were available. Under the circumstances, however, we have adopted the standing height, age, and weight method for the following reasons:

1. Because of the variable, *i.e.*, family characteristics, all methods are approximations. The influence of this factor on individual weight is not measurable; consequently slight miscalculations in the actual nutritional standard make little difference.

2. The weight factor constitutes only one of five factors in undernourishment.

3. It is the most convenient and practical plan.

The word *anemia* is used in preference to pallor, although pallor was the objective sign upon which most of our observations were based. Hemoglobin and blood counts have been made in a few instances. The color of the conjunctiva and mucous membranes is nearly always in agreement with the laboratory findings; consequently, unless patients are markedly anemic or progressively so, observation is the criterion in determining the presence or absence of anemia.

Flabby musculature is taken to mean that state of underdevelopment and lack of tone in the skeletal muscles which permits the cheeks to sag, the biceps to remain soft and unnoticeable on flexion of the forearm, the shoulders to droop, and the whole body to slouch. The shoulders are usually rounded, the individual does not sit straight in his chair, but slumps, and there are often complaints of foot trouble and backache.

Relaxed skin is evidenced by cold and clammy hands and feet. Loose folds of skin are easily picked up over the greater muscles and backs of the hands. There is poor tissue turgor.

The undernourished worker tires easily and grows mentally weary long before his alert, healthy fellow notices the effect of work. When he goes home in the evening he is ready for bed; he does not have the power to recover his strength during the night's rest; he gets up feeling as tired as he did on retiring; there is no refreshment, no zest for the coming day; he is often irritable, frequently absent from his work, and is prone to develop troublesome infections.

On working operations, in which the element of fatigue does not usually enter, it is found that the amount of work done by those who are undernourished is less than the average amount, because of mental weariness and physical weakness. In other instances production may be regulated by the machine, so that the factor of speed is not the criterion; but in these operations the amount of spoilage is apt to be much higher among the undernourished.

There is another physical sign which is frequently present—namely, lack of luster in the eye; but as this may occur in so many other conditions, it is not considered as typical of undernourishment.

The number of operators who are merely underweight, without having the other signs of undernourishment, are numerous in many plants employing women. It is our experience that most individuals in this class, whether or not they show the other signs of undernourishment, are underweight because of one or more of these reasons:

(1) family characteristics; (2) disease; (3) unusual physique; (4) lack of knowledge of proper diet; (5) haste in eating; and (6) carelessness in diet.

Method of Treatment

We are convinced that it is advisable and possible in many instances to increase the weight of those who are 10 pounds or more below standard, so that it more nearly compares with the so-called normal. The method of procedure is essentially that outlined in the previous paper. This is briefly:

1. Determine, by careful questioning, the family physical tendency as to stature.

2. By painstaking physical examination, eliminate disease as the reason for the lack of flesh.

3. Give careful instructions in the hygiene of the alimentary tract.

4. Provide intermediate nourishment at the dispensary, morning and afternoon, in the form of a milk carbohydrate enforced mixture.

5. In selected cases, advise the use of cod liver oil or Blaud's pills.

The formula for the extra food which we have found to be the most suitable, from a standpoint of weight-producing qualities, taste, and digestibility, consists of:

Mellin's Food.....2/3 oz.
Horlick's Malted Milk .....1 oz.
Sweetened cooked cocoa....enough to taste.
Milk.....sufficient quantity to make 10 oz.

This mixture is given to the diet class at 9:30 A.M. and at 2:30 P.M. Various other carbohydrates have been tried—lactose, Karo Korn Syrup or cane sugar, a chocolate preparation, put up by a local dairy, called "400" (this contains 400 calories per pint), and other combinations—but they have all been discarded for the foregoing formula. Occasionally an individual is found who cannot digest this mixture. In such cases whole milk or milk and cream, half and half, is advised.

At the beginning, as was mentioned in the previous paper, the nourishment was given free of charge to all those who were found to be 10 pounds or more underweight. Finally, it was decided that we should ask payment for this service, and we are now charging slightly less than the cost of the materials. Much to our surprise, since a charge has been made for the extra food, many requests have come in from those who have seen others benefited by this procedure, so that our class is now larger than it was formerly when no charge was made.

Physical Examinations

It is our custom to examine all employees every six months. The plan in vogue at the present time is somewhat different from that which was formerly used. In place of calling the workers in alphabetical order for physical examinations, each department is asked to send a group at lunch time to be weighed and measured. After the calculations have been made in order to determine the proper weight for the age and height, all those who are 10 pounds or more underweight are called for their medical examination as a group. This plan has several advantages. In the first place we are convinced that:

1. *Maintenance of weight is one, if not the best, criterion of good health among individuals who are able to work.*

2. The comparison with the weight on previous examination is extremely valuable. It has been found that not many of those keeping their weight are suffering from progressive illness.

3. In addition, by following this plan most of those below normal in weight, who are the potentially sick, are more easily considered as a group, and as such can be watched with greater facility.

Results of Treatment

A favorable and unexpected result of feeding the undernourished is the effect on chronic constipation. With few exceptions, our diet class is benefited in this respect. This cannot be attributed entirely to the milk formula, for in addition to providing extra nourishment, an effort is made to have the employees select food at the cafeteria which is considered to have an effect on sluggish intestines. Then, too, since we have come to realize the importance of the tremendous variation in the length and position of the intestinal tract in the several types of physiques (as suggested by Dr. Joel E. Goldthwait), we are carefully instructing those who have ptosis to lie down after meals, and others, whose alimentary tracts, we judge, are 10 to 15 feet shorter than the supposed normal, to eat those foods which pass through the intestines slowly, in order that proper digestion and absorption may take place.

Can the undernourished be made to gain weight? Yes, nearly always, provided chronic, progressive illness is not the cause of the condition. Can the underweight be made to gain? Yes, in many instances, and we believe with distinct benefit. An increased weight puts a greater margin of safety between them and the chance of developing a chronic disease, especially tuberculosis. The added pounds give confidence and vitality, and frequently make of a poor operator a capable, pleasant asset to the department. The mental attitude of confidence, which is engendered by a normal body, is an invaluable psychological attribute. It frequently replaces that apologetic state of self-pity which is incompatible with a happy existence or with good work.

In this connection, it has been interesting to find that those who are 20 pounds or more overweight are not so efficient as those who are of normal weight or who are underweight, but they are more efficient than those who are undernourished. Their mental attitude, however, is quite different—a proof of the proverbial saying that the fat are good-natured.

In confirmation of the statement made in our first report, we have found that the best results are secured in the group of employees convalescing from illness. If no other reason existed for intermediate feeding, the benefits derived from this phase of preventive medicine would justify its continuance. It is a real pleasure to see the employee who is very anxious to get back on the job after an illness gain weight and strength more rapidly than occurs in private practice, because of systematic extra feeding and rest periods.

We are thoroughly convinced that undernourishment and low efficiency go hand in hand, and that those who are 10 pounds underweight (from other reasons than family characteristics) are often below the average of a department. Among 400 employees, in two years, there have been twenty, or 5 per cent., who were definitely undernourished, and sixty, or 15 per cent., who were 10 pounds or more underweight. Efforts to bring these persons to a normal physical condition have resulted in increased working efficiency in nearly every case. This of course means a saving of dollars and cents to the employer. We do not forget, however, that these benefits stand apart from the more important considerations—prolongation of life, freedom from disease, and a contented, happy existence—factors which cannot be measured.

LEAD STUDIES: VI. ABSORPTION OF LEAD BY THE UPPER RESPIRATORY PASSAGES*

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IN a previous communication (1), it was shown that although the watery extract of the pituitary gland was not absorbed from any other internal or external surface of the body, it nevertheless gained rapid and effective entrance through the nasopharynx. The disclosure of such an interesting physiological mechanism raised the query whether this absorptive power might extend also to particulate matter. Lead was used in the experiments because a trustworthy method for the determination of minute amounts in biological material had been developed (2); the carbonate was chosen because, judging by its importance in producing lead poisoning, it is apparently readily absorbed.

The three portals of entry for lead are usually considered to be the respiratory tract, the gastro-intestinal tract, and the skin. Of these, the last is of admittedly minor significance, for only minute quantities can be absorbed by this route. Practically the entire evidence in support of this possibility is clinical; and in all such cases reported, the ingestion or inspiration of fine particles cannot be excluded.

Authorities differ widely in the comparative etiological importance which they attach to the gastro-intestinal and the respiratory tracts. The outbreaks of plumbism following contamination of water supplies establish the possibility of gastro-intestinal absorption. Most observers agree that the incidence of lead poisoning in any given occupation is roughly proportional to the existent dustiness; but whereas some believe that the dust is inhaled directly into the lungs and is there absorbed, others maintain that the dust first becomes lodged in the upper respiratory passages and is then swallowed. A body of evidence exists, however, that points to another and heretofore unrecognized possibility —namely, absorption from the upper respiratory passages themselves.

The two essential requisites for the entrance of lead through any portal are: (1) deposition of lead on that surface; and (2) absorption from that area.

1. *Deposition of Lead in Upper Air Passages.*—One of the chief functions of the upper respiratory passages is that of filtration. The vibrissae at the entrance to the nose catch the larger particles, while the irregularly shaped nasal passages bathed in mucus impede and entangle any fine dust. This sieving property is well illustrated by the ulcerative lesions occurring in the noses of workers in dry chrome salt, basic slag, and the arsenical green powders. The effectiveness of the nasal passages is even more strikingly illustrated by the comparative absence of pneumokoniosis in the lungs of horses that have lived for ten or more years in dusty mines (3), since horses breathe exclusively through the nose.

In mouth breathers, dust lodges on the mucous membrane of the mouth and posterior pharyngeal wall, but a somewhat higher proportion finds its way directly to the lungs. The work of Leh-

*Received for publication June 1, 1923.

mann, Saito, and Gfrörer (4) is pertinent in this connection. They inhaled dust of definite white lead concentration and found that, when inspiration was accomplished through the nose and expiration through the mouth, only 2 per cent. was again exhaled, 51 per cent. became lodged in the nose, and 3 per cent. was to be found in the washings from the mouth. It seems certain, from the above considerations, that an important fraction of inhaled dust must become lodged in the upper respiratory passages.

2. *Absorption of Lead from the Upper Respiratory Passages.*—No direct evidence exists that such absorption takes place, but the unusually rich blood supply and the close mesh-work of submucosal lymphatics seem to favor such a process. The abundant supply of mucus in the upper air passages may possibly exert a solvent effect on lead salts. Bloomfield (5) found that various strains of bacteria implanted on the normal intact nasal mucosa underwent rapid dissolution and could not be recovered at the end of one to three hours.

Certain phenomena indicating actual absorption of substances are of considerable interest in this connection. Klebs (6) relates that it was an ancient custom among the Chinese and Hindus to vaccinate against smallpox by blowing the finely powdered virus into the nostrils. Similarly Dserzgowsky (7) produced active immunity in animals by administering diphtheria toxin intranasally by sprays and cotton plugs. Blumenau (8) repeated these observations on large numbers of children, using intranasal plugs heavily soaked with undiluted toxin. Like Dzerjgowsky, he found that the procedure caused no subjective symptoms, but was followed by the appearance of a small amount of antitoxin in the blood. These experiments derive additional significance from the fact that Anderson (9) tried in vain to immunize guinea-pigs to diphtheria by subcutaneous injections of toxin.

More exact demonstration of the absorption of substances by the nasopharynx is afforded by the experiments of Sewall (10) on guinea-pigs. Sewall found that if three minims of horse serum were instilled intranasally into guinea-pigs, subsequent intravenous injections revealed that the animals had become either sensitized or immune. In the former group, the first intravenous injection caused speedy anaphylactic death. In the other group of animals, the first intravenous injection produced practically no reaction, and a second injection after an interval of three weeks was likewise withstood. Later work (11) demonstrated that the transfer of immune serum conferred immunity on normal guinea-pigs, enabling them to withstand intravenous injections of horse serum which always proved fatal to controls. As the authors of these experiments realized, however, there was no assurance of the site of absorption of the horse serum, since some may have reached the trachea and some was certainly swallowed.

The only proof of the actual absorption of substances in the nasopharynx is afforded by pituitrin (1). When pituitrin is held in the mouth for fifteen minutes and is then swallowed, or when it is given by rectum or in salol-coated tablets, it proves wholly ineffectual. When it is applied intranasally, however, it checks both the polyuria and the polydipsia of diabetes insipidus quite as effectively as when it is administered hypodermically.

No data exist, however, concerning the absorption of particulate matter from the upper respiratory passages. In view of the foregoing *a priori* arguments, and in view of the susceptibility

of this problem to experimental attack, the following work was undertaken.

Method

Dogs and cats were used. Under ether anesthesia and aseptic precautions, the neck was incised in the midline and the trachea and the esophagus were identified. The esophagus was completely occluded by two or more ligatures, the trachea was opened below the thyroid, and a tightly fitting glass cannula was inserted. The lumen of the upper free end of the trachea was then occluded by two or more ligatures. The wound was closed in the usual way. Finely powdered lead carbonate dust was then sprayed into the nose with an ordinary nasal atomizer fitted to a short piece of small rubber tubing. The amount of dust delivered was estimated by weighing the atomizer before and after use. In order to guard against contamination of the air by the dust, a wet towel was wrapped about the head and atomizer after the latter had been inserted into the nose. The animals were kept in cages and were carefully observed for any signs of tracheal obstruction. Physiological saline or 10 per cent. glucose solution was introduced intraperitoneally. The animals did not survive the operation well, becoming gradually weaker and dying after eighteen to thirty-six hours.

Each animal was carefully autopsied with particular reference to the state of the trachea and the esophagus. The skin was discarded. The esophagus was severed just below the ligatures, the upper portion was washed, and was then filled with water to discover whether the lumen had been completely obliterated. The upper portion of the trachea was similarly tested. In order to make sure that no absorption had taken place via the esophagus or the trachea, the thoracic portion of the esophagus, the trachea below the cannula, and the lungs were analyzed as a group, with particular care. In all the experiments presented below, the ligatures were effective in preventing the passage of lead. To avoid contamination, the animal was then decapitated and the entire head was discarded. The skeleton, the remaining internal organs, the muscles, and the liver including the gallbladder, were each analyzed separately, according to the procedure of Fairhall (2). By this method lead is separated as the sulphide, is redissolved, and is finally estimated as the chromate. The accuracy of this method for minute amounts of lead in biological material has been clearly demonstrated. Of the tissues analyzed, only the skeleton offered difficulties. After successive ashings and extractions, it was frequently necessary to ignite the residue with equal parts of sodium and potassium nitrates. The tendency of the lead to precipitate as the phosphate necessitated the use of tartaric acid according to the directions of Minot (12).

Protocols

Experiment 1.—November 6, 1922. Dog, female. Weight 6.5 kg. At 1 P.M. 0.0075 gm. of morphine sulphate was injected hypodermically. The operation was performed under ether at 3 P.M. A midline incision was made, and the esophagus was completely tied off by four ligatures below the level of the thyroid. A tracheal cannula was then inserted. Two ligatures were tightly applied about the open end of the trachea above the cannula. After the operation 0.48 gm. of finely pulverized white lead was sprayed intranasally. The dog died at the end of eighteen hours.

At autopsy the cannula was found obstructed. The trachea above the cannula, and the esophagus appeared completely occluded by ligatures, and, when tested with water, they did not leak.

Tissue Analyzed	*Mg. of Metallic Lead*
Skeleton	7.5
Lungs, trachea, esophagus	trace[1]
Liver	0.1
Muscle	0.2
Internal organs	0.2

[1]Less than 0.1 mg.

EXPERIMENT 2.—November 13, 1922. Dog, male. Weight 8.4 kg. At 2:10 P.M. 0.0075 gm. of morphine sulphate was injected.

The experiment was performed under ether at 3:40 P.M.; the procedure was the same as in Experiment 1. After the operation 0.41 gm. of lead dust was sprayed intranasally.

After twenty-three hours, the dog was very weak. Five hundred c.c. of 10 per cent. glucose were given intraperitoneally and an additional 0.42 gm. of lead carbonate was sprayed intranasally. The dog died one hour later, twenty-four hours after the operation.

At autopsy, the trachea and the lungs were normal in appearance. Other organs showed no evident abnormality. Both the trachea and the esophagus above the ligatures retained water without leaking.

Tissue Analyzed	*Mg. of Metallic Lead*
Skeleton	22.3
Lungs, trachea, esophagus	trace[1]
Liver	1.3
Muscle	0.2
Internal organs	0.8

[1]Less than 0.1 mg.

EXPERIMENT 3.—November 20, 1922. Cat, male. Weight 2.7 kg.

The usual operation was performed under ether at 3 P.M. The cat was in good condition after the operation. In this experiment 0.18 gm. of lead dust was sprayed intranasally, and approximately 150 c.c. of physiological saline were given intraperitoneally.

After twenty-four hours, under light chloroform anesthesia, approximately 150 c.c. of saline solution were given intraperitoneally and 0.30 gm. of lead dust was sprayed intranasally. Death occurred between thirty and thirty-six hours after the operation.

At autopsy, both lower lobes contained patches of broncho-pneumonic consolidation. The left upper lobe, and, to a lesser extent, the right upper lobe, contained areas of red hepatization. No tracheal obstruction existed. Both the trachea and the esophagus above the ligatures retained water without leaking.

Tissue Analyzed	*Mg. of Metallic Lead*
Skeleton	29.3
Lungs, trachea, esophagus	faint trace
Liver	1.1
Muscle	faint trace
Internal organs	0.2

EXPERIMENT 4.—November 20, 1922. Cat. Weight 3.6 kg.

The experiment was performed at 3 P.M.; the operative procedure was similar in all respects to that used in the foregoing experiments. Immediately after the operation 0.30 gm. of lead dust was sprayed intranasally and approximately 150 c.c. of physiological saline were introduced intraperitoneally.

After twenty-four hours, 0.47 gm. of lead dust was again sprayed intranasally, and 150 c.c. of saline solution were given intraperitoneally. Death occurred between thirty and thirty-six hours after the operation.

At autopsy, patches of pneumonic consolidation were to be seen scattered throughout both lungs. Water was retained in the esophagus and the trachea above the ligatures, without evident leakage.

Tissue Analyzed	*Mg. of Metallic Lead*
Skeleton	23.3
Trachea, lungs, esophagus	none found
Liver	0.5
Muscle	0.3
Internal organs	0.2

DISCUSSION

The lead found in the tissues in the foregoing experiments must have been absorbed in the upper respiratory passages. In all the autopsies, both the trachea and the esophagus were so securely compressed that no leakage of water could be demonstrated postmortem. Final proof of the efficacy of the ligatures in preventing the passage of lead was afforded by the chemical analyses of the organs below the ligatures. In no instance could more lead be demonstrated than was to be expected from the usual distribution found by Minot (12). The average amount of lead absorbed, in terms of metallic lead, was approximately 22 mg. This figure in-

cludes the first experiment, in which the low total may be due to a loss of lead in the analysis of the skeleton.

The presence of an area of such striking absorptive power naturally excites curiosity as to its physiological importance. The work of Sewall (10), previously cited, strongly suggests that nasopharyngeal absorption may play an important rôle in establishing resistance to the "droplet infections." The anatomical design of the upper respiratory passages which prevents the progress of particles to the more vulnerable pulmonary passages, the power of mucus to dissolve organisms, and the ability of the nasopharynx to absorb such decomposition products, constitute a chain of forces splendidly adapted to the creation of natural active immunity.

The exact mechanism underlying nasopharyngeal absorption is not clear. Certain facts are, however, of considerable interest in this connection. Flexner (13) has shown that, after intraspinal inoculation of monkeys with the Diplococcus intracellularis, the organisms can be detected both free and intracellularly in the nasopharynx; and similarly, the virus of poliomyelitis has been demonstrated in the nasal mucosa of monkeys inoculated intraspinally (14). The successful inoculation of poliomyelitis virus into the nasopharynx (15) clearly demonstrates that the nasopharynx may serve also as a portal of entry in certain diseases. Whether absorption is accomplished through the blood stream, through the lymphatics, or through both channels, it is, however, impossible to state.

No information is offered by the preceding data concerning the relative importance of nasopharyngeal absorption in lead poisoning. Certain experiments performed previously by Minot (12) with an entirely different aim bear on this point. Cats, in which the esophagus had been ligatured, received intratracheally from 5 to 10 c.c. of a heavy suspension of lead carbonate. The suspension was introduced while the animals were still unconscious; this facilitated the entrance of the substance directly into the alveoli. These animals, on regaining consciousness, coughed considerably, so that the upper as well as the lower respiratory passages must have received depositions of lead. Notwithstanding the markedly increased area of absorption in these cats, the amount of lead recovered from the tissues was of about the same order of magnitude as in the present experiments—*i.e.*, a range of from 16 to 40 mg., with an average of about 25 mg.

These experiments do not reproduce the situation found in industry. They represent in cats and dogs a sudden exposure to a relatively large amount of lead dust with the exposure limited to the upper respiratory passages down to the larynx. Absorption is probably hindered in the experiments by a large part of the lead dust being lost in the drooling which follows the operation. The nasal mucus is also not concentrated by evaporation as when normal breathing occurs. In spite of these opposing factors, these experiments demonstrate a rapid absorption of relatively insoluble lead particles from the upper air passages sufficient to induce plumbism readily by this portal of entry alone.

Conclusions

1. Particulate matter in the form of pulverized lead carbonate is readily absorbed from the upper air passages of cats and dogs.

2. The absorption is rapid and of a magnitude far in excess of the minimal toxic dose.

3. Absorption in industry of lead salts by the upper respiratory passages would therefore seem to be a definite possibility.

BIBLIOGRAPHY

1. Blumgart, H. L.: The Antidiuretic Effect of Pituitary Extract Applied Intranasally in a Case of Diabetes Insipidus. Arch. Int. Med., 1922, *29*, 508.
2. Fairhall, L. T.: Lead Studies: I. The Estimation of Minute Amounts of Lead in Biological Material. THIS JOUR., 1922-1923, *4*, 9.
3. Rivers, W. C.: Pneumokoniosis in Man and Horse. Lancet, 1919, *2*, 55.
4. Lehmann, K. B., Saito, Y., and Gfrörer, W.: Ueber die quantitative Absorption von Staub aus der Luft durch den Menschen. Arch. f. Hyg., 1912, *75*, 152.
5. Bloomfield, A. L.: The Fate of Bacteria Introduced into the Upper Air Passages. II. B. Coli and Staphylococcus Albus. Bull. Johns Hopkins Hosp., 1920, *31*, 14.
6. Klebs, A. C.: The Historic Evolution of Variolation. Bull. Johns Hopkins Hosp., 1913, *24*, 69.
7. Dserzgowsky, S. K.: Ueber die aktive Immunisierung des Menschen gegen Diphtherie. Ztschr. f. Immunitätsforsch., Ref., 1910, p. 602.
8. Blumenau, N. R.: Ueber die aktive antidiphtherische Immunisation der Kinder nach dem Prinzip von S. K. Dzerjgowsky. Jahrb. f. Kinderh., 1911, *74*, 141.
9. Anderson, J. F.: Hyg. Lab., Washington, 1906, Bull. 30.
10. Sewall, H.: Some Relations of the Brain and of the Olfactory Apparatus to the Processes of Immunity. Arch. Int. Med., 1914, *13*, 856.
11. Sewall, H., and Powell, C.: Studies on the Relations of the Hypersusceptibility and Insusceptibility Induced in Guinea-Pigs by the Instillation of Horse Serum into the Nose. Arch. Int. Med., 1915, *16*, 605.
12. Minot, A. S.: Lead Studies. Unpublished data.
13. Flexner, S.: The Contribution of Experimental to Human Poliomyelitis. Jour. Am. Med. Assn., 1910, *55*, 1105.
14. Flexner, S., and Lewis, P. A.: Epidemic Poliomyelitis in Monkeys. A Mode of Spontaneous Infection. Jour. Am. Med. Assn., 1910, *54*, 535.
15. Landsteiner, K., and Levaditi, C.: Etude expérimentale de la poliomyélite aiguë. Ann. de l'Inst. Pasteur, 1910, *24*, 833.

FURTHER OBSERVATIONS ON THE CONTROL AND PREVENTION OF TETRACHLORETHANE POISONING*

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PREVIOUS observations on this subject (1) have led to the conclusion that symptoms of the very early stages of tetrachlorethane poisoning can be detected by careful observation. These early stages may be accompanied by, and are often preceded by, a particular blood picture, as was discovered by Minot and Smith (2). Proper interpretation of this picture, it was believed, would make possible the prevention of all but very slight cases of poisoning.

The purpose of these additional observations is chiefly to show that these earlier conclusions have been borne out by practical application of their principles over a period of more than two years, and that as a result of their application no serious poisoning from tetrachlorethane has occurred in that time. In fact, only one real case of jaundice has resulted. Furthermore, certain tendencies in the action of this substance on the human organism, which were noted in the previous papers, have become much more definitely understood as time has gone on and as an opportunity has been afforded to watch the same men in contact with the substance over extended periods.

As was brought out by Minot and Smith, in most cases the increase in large mononuclear cells keeps almost exact pace with the appearance of or increase in symptoms. The increase in broken and immature large mononuclears also follows practically the same course. As was noted previously, sudden very heavy doses of the fumes of tetrachlorethane often produce symptoms far in advance of the blood changes and far more severe than are justified by the blood picture. Nevertheless, the blood picture reaches the same degree of severity, although sometimes not until a day later. In other words, the symptomatology curve and the blood curve arrive at about the same peak of severity, but at slightly different times. As can be shown by the citation of single examples and by charting the blood picture, the symptoms follow closely the changes in the blood.

In men who do not seem particularly susceptible at first to the effects of tetrachlorethane fumes, there is developed a certain amount of tolerance to the substance. This tolerance is evident symptomatically, and its degree is perhaps best measured by the appearance of the blood, which often contains as high as 30 to 40 per cent. of large mononuclear cells. With this high percentage of large mononuclears there nevertheless seem to be no severe symptoms and rarely any jaundice. There are occasionally complaints of tired feeling, and much more often of gastric symptoms, such as lack of appetite and a slight feeling of nausea, with possibly a slight headache. At times these symptoms progress to a point which necessitates a vacation from work for three days to a week; at other times they seem to subside of themselves, when a decrease in the blood count occurs.

The practice of allowing the mono-

*Received for publication April 14, 1923.

nuclear count to reach such a height even without symptoms is not one to be encouraged; on one occasion which I recall, however, it was reached rather suddenly as the result of using a new substance in the solution, which made the tetrachlorethane volatilize more easily and gave greater density to the fumes. This substance produced increased and more rapid absorption of the fumes by the men, and its use had to be abandoned on this account.

sion of poisoning. The leukocyte count is useful for comparison with the mononuclear count. Symptoms of poisoning usually begin as the lines of these three counts approach each other; when they cross, actual illness occurs and absence from work is necessary. A very sudden rise and fall in the count generally means a sudden heavy dose of fumes, but no absence from work and only transient malaise of a few hours' duration.

In Figure 3 the smear charted on February 14, 1922, represents the picture of beginning poisoning in which the blood showed 32 per cent. polymorphonuclear leukocytes, 47 per cent. large mononuclear cells, 5 per cent. lymphocytes, 1

FIGURE 1

SYMPTOMS				SMEAR					
STOM.	NERV.	GENERAL	DATE	P.	L.	LMN.	E.	M.	BROKEN PLATES WC

Explanation of the accompanying diagrams will show in detail the method of charting the blood picture in conjunction with the record of symptoms. The sample record which is reproduced may be useful for similar types of industrial work. The record form has on one side a self-evident record of the blood picture on various dates (Fig. 1). The other side has half the space devoted to a general physical examination record (Fig. 2) and the other half left blank to be used for the chart, a sample of which is reproduced in Figure 3.

In actual practice the symptoms are recorded on the form on the date that each blood smear is taken, and at the same time the blood picture for that date is plotted on the chart. For the purposes of this work the important items of the differential count are the percentages of polymorphonuclear leukocytes, of large mononuclears, or endothelial cells as some of us now consider them, and of broken cells. A high mononuclear count —that is, 20 per cent. or over, varying with the individual tolerance—usually indicates poisoning. A large number of broken cells—generally mononuclear cells—seems to indicate rapid progres-

FIGURE 2

Individual Record

Name Address

Age M. W. S. D.

Dependents Workers

Occupational Hist. Lived in

Previous Jobs

Began work

Present Job Transfers

Family Hist.

Personal Hist.
Gen. Dev't.
Ht. Wt. Eyes R. L.
Glasses
Throat Ears Nose
Heart Rate Size Murs.
B. P.
Lungs Abd.
G. U. Neurolog.
Urine Positive Findings

Date

per cent. mast cells, and 15 per cent. broken cells. This picture is accompanied by mild symptoms, such as nervousness, lack of sleep, distaste for food, and a slight noontime feeling of nausea,

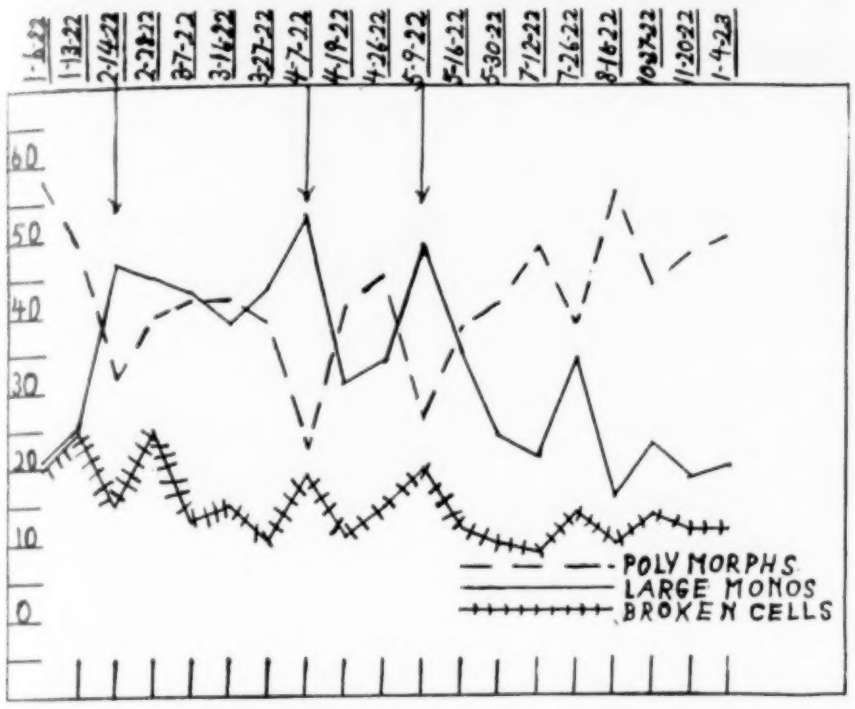

FIG. 3.—Blood chart. Abscissas=dates on which smears were taken. Ordinates=percentage.

together with general malaise. The smear charted on April 7, 1922, represents marked poisoning. At this time vomiting was noted in addition to the foregoing symptoms, and a week's absence from work was necessary. The previous high blood count was remedied in three days. The smear charted on May 9, 1922, represents a blood picture which was accompanied by no symptoms. The picture was deemed sufficiently serious, however, to warrant excusing the individual from work for two days, after which, as will be seen from the chart, the blood gradually returned to normal.

SUMMARY AND CONCLUSIONS

1. A consideration of the blood of persons exposed to tetrachlorethane fumes, and the interpretation of the blood picture are of the utmost importance, and serve in nearly all cases not only to determine susceptibility to the fumes of tetrachlorethane, but also to prevent poisoning and, to a great extent, malaise which results in depreciated industrial efficiency.

2. Aside from one or two easily recognized types of exceptions, the blood picture and the symptoms, which in the early stages are almost wholly gastric and general, follow nearly parallel lines.

3. These observations, together with the original conclusions in regard to the use of tetrachlorethane, seem to emphasize anew the entire feasibility of employing the substance commercially, provided that proper precautions are taken and that use is made of the present available medical knowledge on the subject.

BIBLIOGRAPHY

1. Parmenter, D. C.: Tetrachlorethane Poisoning and its Prevention. THIS JOUR., 1920-1921, *2*, 456.

2. Minot, G. R., and Smith, L. W.: The Blood in Tetrachlorethane Poisoning. Arch. Int. Med., 1921, *28*, 687.

ATMOSPHERIC PARTICULATE MATTER: II. THE USE OF ELECTRIC PRECIPITATION FOR QUANTITATIVE DETERMINATIONS AND MICROSCOPY*

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*Received for publication July 9, 1923.

I. INTRODUCTION

IN a previous article (1) the writers discussed various methods which have been proposed for determining atmospheric particulate matter, and described a new apparatus for determining *dust* as well as a method of calibration. Gibbs' (2) classification was suggested as offering a convenient and universally applicable method for distinguishing atmospheric particulate matter in terms of particle size. According to this classification, which divides particulate matter into three general types, *dusts* comprise solid matter made up of particles greater than 10 microns, *clouds* cover the range of 10 microns to 0.1 micron, and *smokes* comprise the smallest particles, 0.1 to 0.001 micron. The new dust apparatus described in the previous article (1) is admittedly inefficient against the smaller particles covered in Gibbs' second class, clouds (or fumes), while its use against the third class, smokes, is out of the question.

Many problems in hygiene and public health require accurate determinations of clouds (or fumes) and smokes, but up to the present time no satisfactory

method, which is at all universal and at the same time accurate, has been developed. Our dust apparatus (1) is best suited to Gibbs' first class and to part of his second. The apparatus with which this paper is concerned is intended more particularly for the remainder of his second class and for his third, though it can also be used for the determination of dust.

Electric precipitation offers a method whereby both microscopic and chemical analyses can be carried out on the same sample precipitated dry on a thin transparent sheet of a substance such as celluloid. So far as we are aware, no method exists at the present time which will accomplish this double and, we feel, highly desirable purpose. Furthermore, photomicrographic studies of precipitated samples indicate that by means of this procedure the sample may be placed in the field of the microscope in the same state of dispersion or flocculation in which it existed in the air prior to precipitation. It is unnecessary to wet the sample with water or any other medium before examining it under the microscope.

The fundamentals of the method and of the apparatus that we propose are by no means new. The fact that the general principles have not been used in the past appears to be due to an impression that the apparatus is complicated and dangerous because of the high voltages, that it is too cumbersome to be portable, and finally that it is too expensive. It is hoped that this paper will help toward dispelling such ideas which, as is evident from the literature in this field of research, still exist.

Our chief objection to past methods of electric precipitation is that they have, with one exception, required the use of rectified or unidirectional high tension current. Unquestionably, quantitative precipitation at high efficiency can be effected by means of rectified current regardless of whether the rectification is obtained by mechanical means or by a rectifying valve such as the kenotron. The use of a rectifying device complicates the apparatus and adds to its cost. For a small scale portable or permanent laboratory outfit we are not convinced that complete rectification is necessary. In fact, it appears probable that better results may be obtained without either a mechanical rectifier or a kenotron in the circuit. This article presents an account of the development of a small electric precipitator, together with a detailed consideration of the difficulties which may be encountered in its use.

II. Theoretical Aspects of Electric Precipitation

The development of the widely used Cottrell process has been described in both its theoretical and its historical aspects by a large number of writers. The accounts of the early experiments of Lodge (3) (4) and more particularly of Cottrell (5) contain sufficiently complete bibliographies. These can be supplemented with the more recent bibliographies of those concerned with the construction or operation of Cottrell plants (6).

1. *The Flocculating Action of Alternating Current*

Lodge refers to an experiment performed by Hohfield, in 1824, which illustrates the action of high tension alternating current in clearing up smoke in a confined space. A glass bottle is filled with smoke such as that from a cigarette or, better, with a white fume like ammonium chloride. The high tension leads from a transformer are allowed to hang

in the bottle through two holes in a rubber stopper, and when the current is turned on the smoke quickly clears up. The wires must be sufficiently distant from each other to avoid the passage of a disruptive discharge. The resultant clearing of the smoke appears to be due to at least two causes: (*a*) the ionizing effect of the corona discharge from the two wires; and (*b*) the action of the electric wind which can be made violent enough to blow some of the smoke out of the top of the bottle. Deposits on the walls of the container form curious patterns such as may be obtained with iron filings subjected to a magnetic field. The particles are obviously flocculated. The two wires, on the other hand, are covered with the deposit in about equal amounts and show no evidences of flocculation. It seems probable, therefore, that the deposit on the wires is due to precipitation, while that on the bottle more truly represents flocculation caused by the electric wind and by the alternating character of the ionic discharge from the wires.

2. *The Cottrell Process*

The Cottrell process utilizes unidirectional current rather than alternating current. It is explained by Cottrell (5) somewhat as follows. If a unidirectional current at high potential is applied between a point and a plate, placed near enough together to allow the passage of static discharges but far enough apart to prevent sparking, the intervening air takes a charge of the same sign as the point. Cottrell found it more effective to make the point the negative and the plate the positive electrode. A later development showed that the same result was achieved by using a wire, centrally located in a metal pipe, as the negative and the pipe as the positive terminal. For our purposes a consideration of this latter type only is necessary.

If smoke or other fine particles are present in the space between the wire and pipe, they will act as carriers of the electrons produced by the corona or ionic discharge from the wire, and will be driven, probably largely by the force of the electric wind, to the pipe where they are deposited. In Cottrell plants the pipe is always grounded, presumably for safety. It is stated by many other writers that the best results are obtained when the wire is made the negative pole. Nesbit (7) gives the relative precipitating efficiencies of negative, positive, and alternating current coronas as 95 to 98 per cent., 70 to 80 per cent., and 50 per cent., respectively. Tolman and Karrer's (8) photographic evidence seems to support the contention that the negative corona exerts the greatest precipitating force. Formulae given by Strong (9) and Saget (10) show that the intensity of the static field is a function of the logarithm of the ratio of the radii of the two electrodes. Since the radius of the wire or precipitating electrode occurs as the denominator and the collecting electrode as the numerator in this fraction, the intensity of the electrostatic field can be greatly altered by changing the size of the precipitating electrode. For small precipitators of the type in which we are interested it is advisable to use fine wires. A slight change in the size of the wire exerts a marked effect on the capacity of the precipitator, while a slight change in the diameter of the collecting electrode, on the other hand, has little effect on the intensity of the field and, therefore, on the precipitating capacity of the apparatus.

Whether rectification is obtained by a mechanical rectifier or by a valve, the net result is much the same (11) (12). Both devices, with somewhat different

individual characteristics, pick off or rectify the upper or positive half of the voltage and current curves, and deliver this rectified current to the precipitator. Neither device utilizes the lower or negative half of the current or voltage curves. One of the most important and expensive features of large Cottrell plants is the rectifying equipment, which is usually of the mechanical type. For small laboratory units it has been shown by Tolman, Reyerson, Brooks, and Smyth (13) that the kenotron gives satisfactory rectification, and that quantitative precipitation of materials such as tobacco or other smokes can be obtained with their precipitator. Bill (14) used a mechanical rectifier in designing a small laboratory unit, but the kenotron, as used by Tolman, unquestionably gives a more satisfactory method for small units. Both methods, however, add to the complication of the apparatus, while the kenotron adds materially to its expense.

3. *Lamb, Wendt, and Wilson's Precipitator*

It was shown by Lamb, Wendt, and Wilson (15) that 100 per cent. precipitation of ammonium chloride fume could be obtained without the use of either a kenotron or a mechanical rectifier. It is sufficient to use a fine wire for the precipitating electrode, and a glass tube for the collecting electrode. The glass tube is wrapped with a fine wire mesh or metal foil, and the two terminals of a source of high tension current are then connected to the foil and to the central wire. Lamb, Wendt, and Wilson (15) used a storage battery and induction coil as the source of high tension current. Our method is essentially the same, excepting that we use larger glass tubes with greater dielectric strength, while the source of high tension current is a transformer which varies in size according to the size and the character of the sample to be taken. (The constructional details are given elsewhere in this paper.)

Shibusawa and Niwa (16), in 1920, published a paper which has been very useful to us in this work. Their apparatus, as well as the voltages used by them, is not unlike ours. We use a glass collecting electrode and a metal precipitating electrode. Their precipitator is similar, except that they cover their experimental precipitating electrode with glass and thus obviate a number of practical difficulties which we also have encountered. They use a kenotron, however, to obtain rectification, and do not appear to have carried out any experiments on precipitation without such rectification, although they give oscillograms taken without a kenotron in the circuit.

We have taken no oscillograms with our apparatus. With their induction coil, Lamb, Wendt, and Wilson suggested that the dielectric strength of the glass was sufficient to cut out the lower or negative part of the current and voltage waves and to let through only the peak or positive portion. It is probable that, with a transformer and a 60-cycle current, oscillograms for our apparatus would be much like those of Shibusawa and Niwa when no kenotron was used. Their curves show that the dielectric strength of glass is insufficient to produce complete rectification. Since our precipitating efficiencies without a kenotron, as evidenced by our experimental results, are as high as those attained by Tolman, Reyerson, Brooks, and Smyth (13) and by Shibusawa and Niwa (16) with a kenotron, we conclude that it is not essential to use unidirectional current.

III. Practical Aspects of Electric Precipitation

1. *The Overloading of Electric Precipitators*

A smoke particle passing through a high tension precipitator is subjected to at least two distinct forces: (*a*) the force of the air stream carrying it along the tube; and (*b*) the force of precipitation tending to drive it at right angles toward the walls of the tube. Actually, the force of precipitation begins before the particle reaches either of the electrodes, since the electric wind and the force of ionization from the corona discharge of the precipitating electrode are active in all directions. Let us assume, for the moment, that the electrostatic field begins at the point where a horizontal plane through the precipitator tube would just cut the beginning of both electrodes. Then, if the intensity of the electric field is great and the air speed is low, the smoke particle will hit the collecting electrode at a point near the bottom or beginning of the electrodes. The distance which the particle travels before precipitating will indicate the relative strength of the field and of the air velocity. When the field intensity is too low or the air velocity too great, the particle may pass out without precipitation. If, on the other hand, the intensity is increased or the air velocity reduced, the particle will precipitate in the tube.

Suppose, now, that the number of particles are increased, but that the precipitator is run at a field intensity and an air speed adequate for precipitating but one particle. It is reasonable to assume that, if the electrostatic force does not keep pace with the number of particles, some of the particles will pass through without precipitating. If, however, the field intensity is increased or the air speed reduced, it should be possible again to effect complete precipitation.

Together with field intensity, air velocity, and the number of particles, the effect of particle size should be considered. It has been shown by Tolman, Vliet, Peirce, and Dougherty (17) that there are limits to the optical intensity of Tyndall beams produced in such atmospheres as tobacco or other smokes. They account for this in terms of particle flocculation. Any force, such as wind, which drives the particles about and increases their chances of colliding with one another or with the walls of the containing vessel, will increase the rate of flocculation. If the smoke stream is made too dense, the particles will collide without being subjected to other forces, and will thus decrease their degree of dispersion as well as their number. Obviously it is possible to make a much denser cloud of smoke than of fine silica particles, as the latter are many times greater in size and will collide with greater readiness. If precipitating capacity, therefore, is governed by the number of particles rather than by their weight, it should be easier to overload precipitators with a stream of tobacco smoke than with silica dust. This is precisely what happens in the small units such as we are using. Discussions of large Cottrell plants indicate that one substance is occasionally found to be more difficult to precipitate than another, but we have discovered no attempt to show this in terms of smokes or other substances made up of particles of determined size. Occasionally there are references to the need of humidification in order to precipitate fumes such as zinc oxide. It can be shown in the laboratory that this promotes particle flocculation and, therefore, that a humidified fume is made up of less in-

dividual and discrete particles than is a dry fume. If our explanation is correct, the humidified fume should be the easier to precipitate, although the collected products represented by the two methods might well be of like weights when considered on the dry basis.

To sum up, then, the factors to be considered in overloading are (*a*) electrostatic field intensity, (*b*) air velocity, and (*c*) particle number. Factors of less importance but not to be overlooked are (*d*) the radii of the electrodes, (*e*) the length of the electrodes, and (*f*) the thickness, density and dielectric strength of the walls of the glass collecting electrode.

2. *The Production of Smoke, Fume, and Dust Streams*

Three substances which are believed to be fairly representative of particulate matter of both hygienic and industrial significance were selected for calibration purposes. Tobacco smoke was made by burning sticks of the composition described by the Bureau of Mines (18) and also by burning cigarettes; ammonium chloride fume was produced by the arrangement shown in Figure 1; and silica dust by that shown in Figure 2, the essentials of which were copied from the Bureau of Mines. Wells and Gerke (19) found that tobacco smoke, produced by burning these special sticks, consists of very uniform particles with an average diameter of 0.27 micron. Cigarette smoke is probably comparable as far as particle size is concerned, but it shows less uniformity. The tobacco smoke particles are unquestionably much smaller than those from ammonium chloride fume of which the average diameter is about 1 micron or less (20), depending on the method by which the fume is formed. An average diameter of 3 to 5 microns was calculated for 250 precipitated silica particles.

In the case of all three substances, it is best to filter the streams before they enter the precipitator. This increases uniformity and eliminates big particles and flocculates. Tobacco smoke should also be passed through a suitable drying reagent before it reaches the precipitator. Otherwise a considerable amount of condensed moisture is precipitated. Drying serves to reduce the amount of moisture but, in our work, does not totally eliminate it. An ammonium chloride fume generator of the type shown is preferable to one having ammonia and hydrochloric acid bottles in series. The latter is apt to clog and tends to give a preponderance of flocculates, which soon stop up the cotton filter. For producing uniform silica dust streams, the settling funnel and filter permit the use of undried air and silica. Without using both devices, however, it was impossible to produce uniform streams with undried air.

Tobacco smoke is intended to represent such smokes as rosin, oil, etc. Ammonium chloride fume seems comparable to the metal oxide fumes produced in metallurgical processes which involve heating the molten metal in an oxidizing atmosphere to a point at which appreciable vaporization and subsequent oxidation result. Silica dust represents fine dusts produced by processes involving crushing, grinding, and drilling operations, and of the three types it is the only one which readily settles out of still air such as is found in a closed room.

All three of these methods permitted variation of (*a*) the electrostatic field intensity, (*b*) the air velocity, or (*c*) the concentration, either independently or in any desired combination. As has already been pointed out, these three factors are the important ones to be considered in overloading the precipitator.

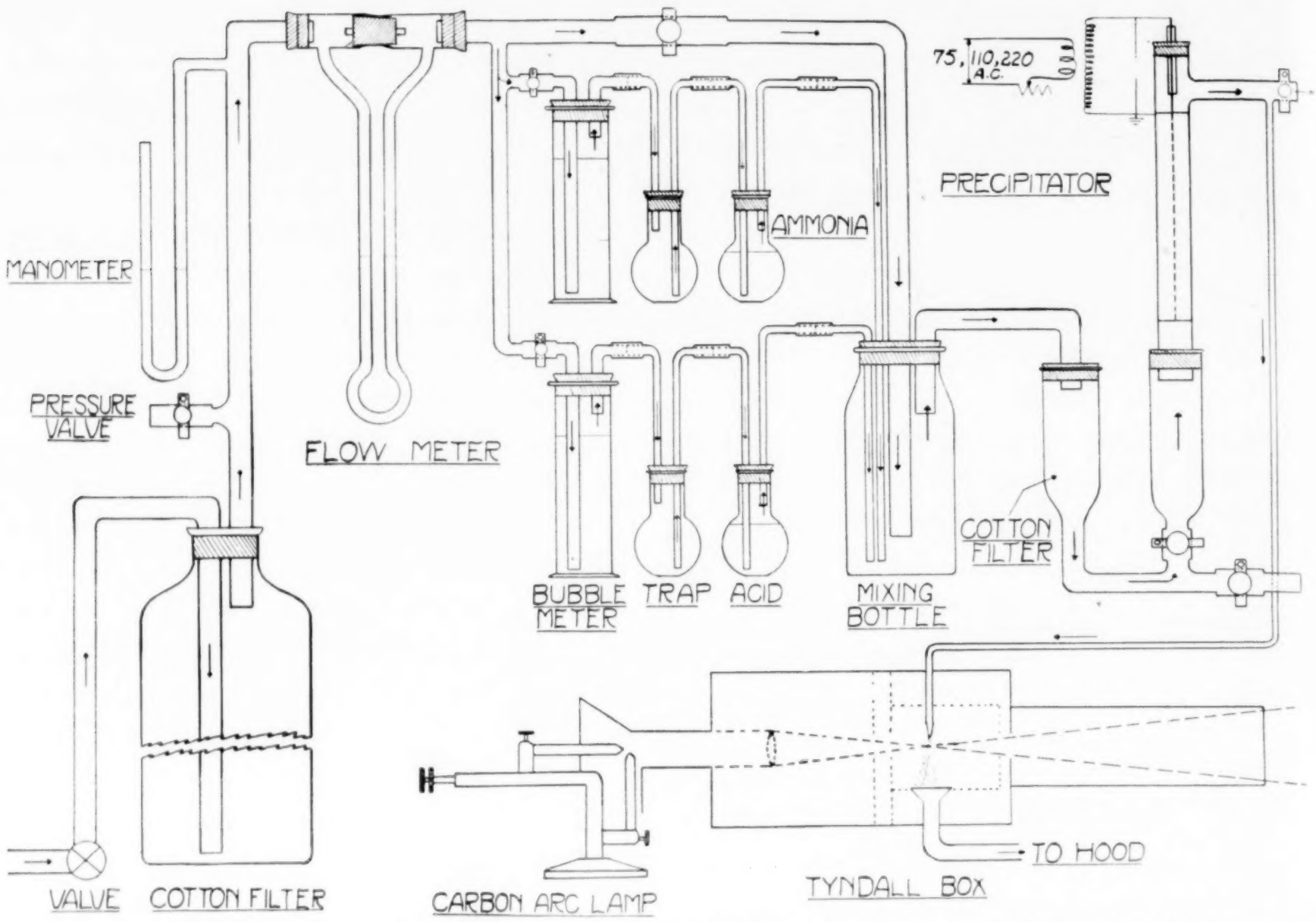

FIG. 1.—Apparatus for calibrating electric precipitators showing ammonium chloride fume generator, electric precipitator, and Tyndall box.

The less important factors, (*d*) the diameter of the electrodes, (*e*) the length of the electrodes, and (*f*) the thickness of the walls of the glass collecting electrode, were determined by trial.

3. *The Efficiency Calibration of Electric Precipitators*

a. The Tyndall Light Beam for Matching Smoke Streams.—It has frequently been shown that the Tyndall light beam can be used as a delicate means of detecting the presence of smoke or other fine particles in a gaseous or liquid medium. A neat and simple application of Tyndall's principle was worked out by the Chemical Warfare Service (21) and has been improved by the Bureau of Mines (18), notably by the addition of Oberfell and Mase's (22) ingenious device for insuring the delivery of constant amounts of air or other gases. As the apparatus has been very fully described and illustrated with detailed drawings, it is unnecessary to go over the ground again. It is sufficient to say that the method is based upon the comparison of the intensity of a Tyndall light beam, from the exhaust side of the filtration device under test, with a like beam made by diluting the smoke, fume, or dust (before filtration) with known amounts of filtered air. By using the regulating device to secure constant air flows of the unfiltered smoke, a definite and constant volume of smoky air is assured, and the quantity of smoke-free air used to dilute the unfiltered smoke stream will not affect this constant stream. By calibrating in percentage the flow meter, through which the pure air passes before meeting the unfiltered smoke stream, the optical filtration efficiency can be read directly.

There are limits, however, to the sensitivity of the apparatus—limits which have been placed by the Bureau of Mines as beginning at about 98 per cent. This method is also of doubtful value in detecting differences as low as 2 per cent., no matter which way the range may be. Obviously, if the filtration device under test is efficient enough to render the stream of smoke invisible, the method cannot be applied, since there

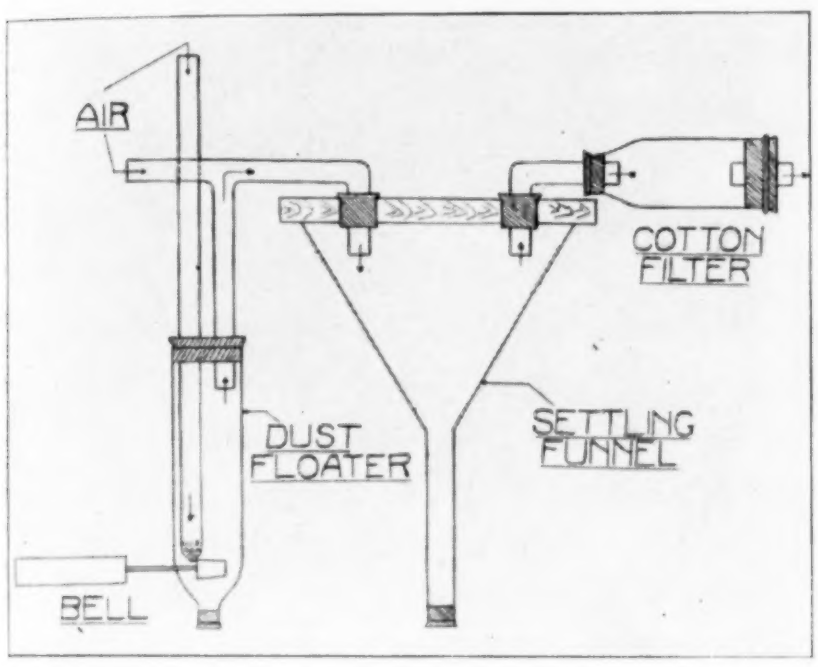

FIG. 2.—Silica dust cloud producer.

are no streams to compare. Electric precipitators can easily be made to work at an efficiency of over 98 per cent. with most substances. We were obliged, therefore, to increase the sensitivity of the Tyndall test although the Bureau of Mines has left little room for improvement.

Figure 1 shows our modification of the Tyndall box. In place of a low voltage, 40-candle-power lamp, we use a carbon arc lamp and focus the light by means of a lens to a thin beam, which passes into a compartment lined with velvet and then out into the room by way of a 4-inch brass pipe coated dead black on the inside with lamp smoke. Velvet is thrown over the pipe at the point where it meets the box in order to keep out the light. The stream from the precipitator passes into the box at right angles to the beam from the carbon arc, and crosses the latter in a beam about 2 mm. wide. At the point of crossing, the carbon arc beam is about 5 mm. wide. When smoke is present, the stream is visible for a distance of about 1½ cm., the most intense light being at the point where the two beams cross.

As this method does not give percentage readings, there is no use in metering the amount of air flowing through the Tyndall box. We used the Bureau of Mines equipment, therefore, merely to determine our optical sensitivities, and then simplified the apparatus to that shown in Figure 1. The box must be exhausted, though not too forcibly, by a suitable pump, and when the precipitator begins to work properly the pump may be discontinued.

With the intense light obtained from a carbon arc lamp, it was found impossible to obtain a dead black region in the box if the smoke nozzle pointed toward the source of light. The nozzle always reflected light, and there seemed no way to avoid this unless the two beams were made to cross. When this is done, the point of the nozzle can be placed close to the main beam and yet be barely visible until smoke appears in the stream from the precipitator. Unless most elaborate precautions are taken in the laboratory, there will always be a very slight but visible beam from the carbon arc lamp. By using a stream from the precipitator of 4 to 5 liters per minute we obtain a definite, sharp black line cutting across the arc beam. Slight and immeasurable traces of smoke will cause the sharp definition of the black line to disappear at a point distinctly before the presence of smoke can be identified with certainty. The sharp black line was used in all determinations of precipitator capacities.

It is reasonable to assume that this gives a detection test which is very close to 100 per cent. It is best, however, to run the precipitators with a decided margin of safety, and so we normally allow an air speed about 10 per cent. lower than is necessary, in order to avoid a visible stream crossing the main arc beam.

b. The Distribution of the Collected Precipitate.—Tolman and his associates (13) have described a simpler test for overloading in both field and laboratory work. They collected their precipitates on thin aluminium foils, while we use celluloid. In either case, if precipitation has been efficient it will show a fairly definite line at the beginning, then 2 or 3 inches collected at maximum intensity, followed by a gradual tapering off until no traces are visible even under the microscope (see Figure 6). Since the foil does not extend the full length of the precipitating electrode, there may be slight but detectable precipitation above the celluloid foil. This will appear as a thin film on the glass collecting electrode and usually on the capillary holding the precipitating electrode. The detection of overloading by alterations in the distribution of the precipitate allows, therefore, a reasonable factor of safety. The test is a little more sensitive than the Tyndall test, as we applied it, but not so convenient since the foil cannot be observed until the run is over.

In field work it is sufficient to stand by the precipitator tube and watch for the appearance of a precipitate above the aluminium foil which is wrapped around the glass electrode. If a precipitate is visible, it is safe to conclude that the run has been at less than maximum efficiency.

It is admitted that neither of these tests definitely proves that precipitation has been complete. For either laboratory or field work, however, we have found that errors from other sources, such as incomplete drying or inaccuracies in weighing, are greater than any possible error from assuming that either of the two methods described shows 100 per cent. precipitation. Lamb, Wendt, and Wilson (15) and Shibusawa and Niwa (16) used ammonium chloride in calibrating their precipitators. The first group determined their efficiencies on the basis of the ammonia content of the entering and escape air, while the latter group determined the chloride content in like samples. Both methods presuppose that the hydrochloric acid and ammonia gases unite to form ammonium chloride and leave no free acid or alkali. Since ammonium chloride is a weak compound and readily dissociates, it is improbable that the reaction goes to completion unless a substantial excess of one of the two reagents is present. In other words, the escape gas may show the presence of both free hydrochloric acid and ammonia. While Lamb, Wendt, and Wilson obtained 100 per cent. recoveries, Shibusawa and Niwa's curves always show less than 100 per cent. Failure to obtain 100 per cent. formation of ammonium chloride fume may possibly account for this.

By using the light beam method and the distribution of the precipitate, we avoid this difficulty with our apparatus. We do not, however, avoid the possibility of the dissociating action of the corona discharge from the precipitating electrode. At the comparatively low voltages at which our experiments have been made it seems improbable that this factor is of importance. In any case, the dissociating action of the corona need not be considered in the case of dusts, and probably not in the case of tobacco

smoke. We obtained no evidence that precipitated ammonium chloride was affected by the corona.

IV. Discussion of Constructional Details and Operation of the Electric Precipitator

1. *Transformer and Electrical Connections*

For a portable apparatus it is essential that the transformer be as light as possible. We use two types, one rated at 10,000 volts and weighing 30 pounds, and the other a more powerful one rated at 20,000 to 25,000 volts and weighing 50 pounds. In either case the transformer has sufficient internal resistance to permit connecting it directly into a standard alternating current lighting circuit. If alternating current is not available, a small converter is used to supply alternating current at 75 volts. It is advisable to make both transformers for 60 cycle current, the usual type met in industrial work. Since a current of 75 to 220 volts may have to be used, the transformers may be wound for current at 75, 110, and 220 volts.

Any suitable rheostat may be used in the primary circuit and should always be available as it furnishes the most satisfactory method of controlling the electrostatic field intensity. Low amperage fuses may be added on the primary side as a protection for the transformer. A switch of any convenient type should be placed in the primary circuit. Single-throw, exposed switches are advisable in order that the operator may know when the circuit is open and closed.

One high tension or secondary lead is connected to the precipitating electrode, and the other to the aluminium foil wrapped around the glass collecting electrode. It is probably better to ground the latter for the protection of the apparatus, but grounding seems to have no effect on the operation of the precipitator. Both high tension leads should be kept dry and well insulated in order to cut down surface leakage. Such insulation is not a safe protection against electric shocks, and consequently the leads and the precipitator should never be touched unless the switch is open. It is advisable to enclose the transformer in a watertight wooden or hard rubber box. The larger transformer should be immersed in oil. All such transformers usually have a safety spark gap on the apparatus and it is, therefore, unnecessary to place another in the circuit. An approximation of the secondary voltage can be obtained from the primary voltage and the winding ratio. This is not required, however, in field work.

2. *Air Flow Meter*

It is usually more convenient in the laboratory to blow the material to be precipitated through the precipitator, and then to measure the volume with a flow meter. For field work, however, the air must be drawn through; for this purpose we are at present using a small high speed universal sewing machine motor which drives a fan with a capacity of about 65 liters per minute at full speed, and is equipped with a rheostat for controlling the air flow. Any accurate low resistance flow meter serves to measure the air passing out of the precipitator. We prefer an orifice meter of the type described for use with dust collectors (1), though we have used glass flow meters of the type shown in Figure 1. The resistance of the precipitator to air flow is very slight. Positive pressure fans, therefore, are unnecessary and the fan and motor can be made light. Ours weighs 5 pounds, and could doubtless be made lighter if desired.

It makes no difference in the operation of the precipitator if the tube is turned upside-down or on its side. For the sake of uniformity we run the precipitator with air entering at the bottom.

3. *The Collecting Electrode*

Pyrex glass is the most suitable substance that we have found for the collecting electrode. Soft glass tubes are more fragile and too easily punctured at high voltages; while clear quartz tubes, which, it has been suggested, would probably be still better, are too expensive. Other substances with comparable dielectric strengths could doubtless be used but, for our purposes, Pyrex glass is satisfactory. The constructional details of other types of tubes are given in Figures 3B, C, and D.

The optimum thickness and diameter of the glass tube have not been definitely determined. As long as the walls of the tube are thick enough to prevent puncturing by disruptive sparks, a slight difference in their thickness causes no appreciable alteration in the capacity of the precipitator. For some reason, however, thin tubes appear to have a greater tendency to heat up than do thick ones, and this is an objection when celluloid foils are used. We have never had Pyrex tubes with 2 mm. walls rise above comfortable hand heat in the course of a twenty-minute run with approximately 18,000 volts on the transformer.

Lamb and his associates used a wire mesh around their precipitator tube. While our precipitators work well with wire mesh, we prefer aluminium or tin foil, and strap it as tightly as possible to the glass with friction tape. Precipitation can be effected in a slight degree if only a single loop of wire passes around the glass tube. The best results are obtained when the tube is wrapped tightly with a good conductor, though it appears to matter little what this conductor is.

4. *The Precipitating Electrode*

Tolman (13) and Bill (14) required their precipitating electrode to be supported at both ends. If one of these two supports can be omitted, it is then possible to withdraw the electrode without danger of touching the precipitate. If the precipitate is to be collected on a celluloid foil, the foil can be withdrawn first without disturbing the slight precipitate on the collecting electrode. Our standard tube (Figure 3A) is used with the precipitating electrodes supported at the upper end only. The precipitating electrode is of stiff steel and is 0.03 inch thick. Though thinner electrodes give a more intense electric field and, consequently, greater capacity to the precipitator, they are supple and render central alignment impossible. While lack of perfect alignment will not necessarily induce sparking, the intensity of the discharge is reduced by its localization at the point where the wire approaches the tube, and thus the precipitating capacity of the tube is reduced. The factor of safety in precipitation is great enough, however, to permit the use of thin rods supported at only one end, and still to allow complete precipitation. With such rods perfect central alignment is never obtained.

The rod is supported at the top of the tube by inserting it through a glass capillary (soft glass can be used), bending it over at the top, and plugging the capillary hole with a substance such as *plasticine*. Tolman used paraffin, which serves just as well. Rubber stoppers are used to support the glass capillary and to plug the hole at the top of the tube. When powerful transformers are used, considerable amounts of ozone are produced which attack the rubber stoppers

and cause them to deteriorate rapidly. There is no reason why a metal holder in place of a rubber stopper cannot be used for the precipitating electrode.

radius. We have tried both Tolman's and Lamb's methods and have found a slight increase in precipitating capacity but not enough to warrant their use.

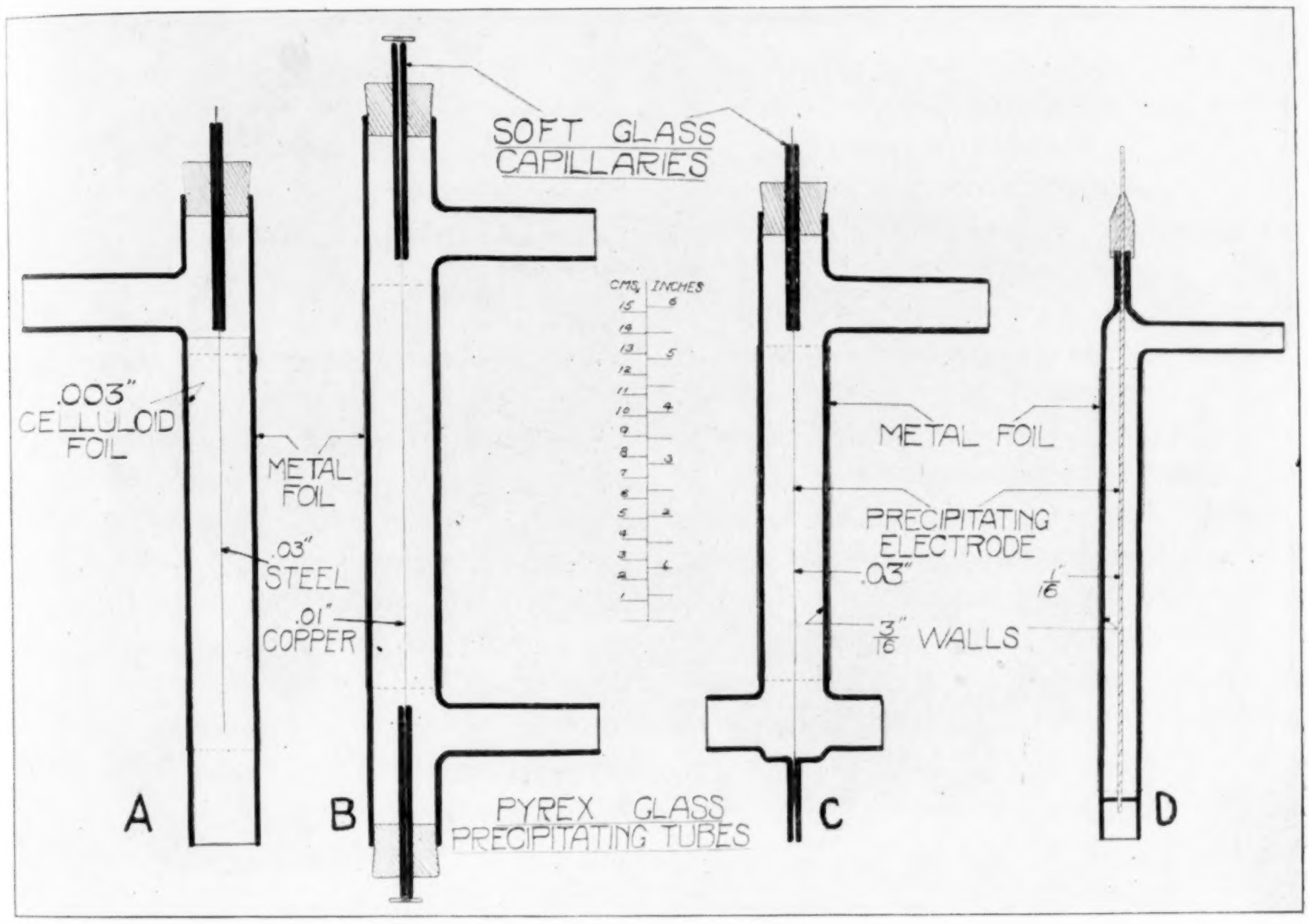

FIG. 3.—A, standard tube for microscopic and gravimetric sampling. B, tube for smoke determination. C, tube in which precipitate is recovered by washing out tube. With celluloid foil, tube can be used for photomicrography. D, tube for fumes. Washed out when inverted.

Tolman, Lamb, and the Bureau of Mines, all recommend a precipitating electrode bristling with points. Tolman's electrode was made by threading a fine platinum wire, while Lamb's consisted in twisting several adjacent wires from a fine mesh gauze so that the short cross wires protruded radially and furnished a vast number of small sharp prickly points. The effective radius of the electrode was then increased, and any advantage gained in producing a more intense discharge through the use of the points seemed to be about counterbalanced by the resultingly increased

5. *Controlling the Location of the Precipitate*

The point at which precipitation begins in our apparatus can be controlled by adjusting the positions of the outer metal foil and of the inner electrode, particularly the latter. When celluloid foil is used inside the tube, it is best to have the foil cover the entire distance to the side outlet of the tube and to place the outer metal foil about 1½ inches up from the bottom of the glass tube. The wire is then adjusted near enough so that the end of it can be seen in order to make adequate central alignment certain.

6. *The Elimination of Disruptive Sparking*

An advantage of this apparatus over Tolman's is the almost total elimination of disruptive sparking. In Tolman's apparatus the secondary voltage is gradually stepped up to a point safely below that at which disruptive discharge occurs. Lamb points out that the use of glass tubes without a rectifier eliminates sparking, and that the tubes, therefore, do not require perfect centering of the precipitating electrode. This is increasingly true when greater voltages and more intense fields are used. It would be impossible to use material like celluloid in our tubes if serious sparking occurred. The only occasions on which we have been troubled by sparking were when thin glass tubes were employed or a tube in which there was a fine blow hole, air bubble, or other defect.

7. *Precipitation on the Central or Precipitating Electrode*

In descriptions of both large and small Cottrell plants there is usually some mention of slight but definite precipitation on the precipitating electrode, and a statement to the effect that it can be greatly reduced by the use of intense coronas. This precipitation always occurs with our device, and the degree to which it occurs can be controlled by the diameter of the inner electrode. While it seems impossible to reduce it completely, the smaller the radius of the inner electrode, the less the precipitate collected on it. This is probably due in the main to the greater intensity of the field when fine wires are used and not simply to the decreased surface area of the fine as compared with the coarser wires. From the practical standpoint we admit that this precipitate is objectionable. Precipitation occurs with such force, however, that light dry fluffy materials, such as fine silica dust or ammonium chloride fume, adhere strongly to both the wire and the foil.

8. *Special Tubes for Determinations Not Involving Microscopy*

Two types of tubes which are satisfactory for fume and smoke determinations are shown in Figures 3B and 3C. It is possible to use celluloid foils with both, but the entire precipitate is not collected on the foil. With these two tubes the foil collection is best adapted to qualitative sampling for photomicrography; if the tubes are washed out after a run, however, they can be used for quantitative determinations as well. The tube shown in Figure 3D has been used frequently for determining ammonium chloride fume, which, when once precipitated, is very soluble in water although the freshly formed fume itself will readily pass through water. It will be noticed that the precipitating electrode is centered by means of a glass cross-piece with a hole in the middle. It might be expected that this would offer a short circuit for the static discharge, but no such effect has been noticed. The capacity of this tube is about the same as that of the tube shown in Figure 3C. The tube in Figure 3C requires side arms for the air entrance long enough to prevent arcing around to the aluminium foil. Both tubes possess an advantage over the standard type shown in Figure 3A, in that they permit the use of fine wires for the precipitating electrode, since the latter can be pulled tight by any convenient means and thus centered. As has already been stated, the capacity of the precipitators is increased by using fine wires instead of thicker stiff rods. Also, the fact that tight wires do not shake from the effect

of the static discharges at high voltages is another advantage. Shaking brings the loose end of the wire or rod nearer the sides of the tube and seems to cut down the field intensity, since the effective radius of the tubes is then lessened. This phenomenon appears to be a reproduction, on a small scale, of the *static surges* often mentioned in the literature on Cottrell plants.

9. *The Celluloid Foil*

Celluloid is not used because of any specific electrical properties, but it is recommended simply because it is transparent, thin, and of the proper stiffness or springiness to fit snugly against the inside walls of the glass tube. If it does not fit tightly, the precipitate tends to accumulate on the portions nearest the wire, and thus indicates that the effective radius of the tube is reduced. This reduction is uneven and should, therefore, be avoided. A disadvantage in the use of celluloid is the low temperature at which it becomes plastic and then sticks to the tube. In drying precipitates for weighing purposes, this feature necessitates the use of drying trains instead of a constant temperature oven.

The extreme inflammability of the celluloid has not caused trouble. A foil has been punctured occasionally when the voltage was too high, but this can be avoided by watching the corona discharge at the top of the precipitating electrode and, by means of the primary rheostat, adjusting the secondary voltage to give safe field intensities. Puncturing may occur equally readily with less inflammable foils such as viscose or cellulose acetate. If the precipitator is to be run at temperatures too high for celluloid, thin mica sheets may be used. They are very fragile and difficult to handle, however, and are usually covered with scratches which interfere with photography and microscopy. The fact that mica possesses a high dielectric strength does not seem to cause difficulties.

It is important to allow an extra length of foil (about 1½ inches) at the lower entrance to the tube; otherwise, some of the precipitate will deposit on the glass. After a run it is sometimes necessary to pry the foil loose from the glass with a knife. It can then be slipped further up the tube and stoppers can be inserted at the tube entrance and at the outlet of the side arm. Then, unless the tube is rapped smartly, the precipitate is not easily dislodged from either the foil or the wire. If handled with reasonable care, such tubes can be transported from the field to the laboratory without spoiling the sample for microscopy.

The celluloid foil which we have found most satisfactory can be obtained as a standard product from the Celluloid Company, Newark, N. J. It is 0.003 inch thick, clear and sufficiently free from surface defects, and inexpensive.

10. *The Effect of Varying the Size and Number of Electrodes*

a. The Length of the Electrodes.—One might expect that the capacity of a precipitator could be much increased by increasing the length of the electrodes and thereby allowing a longer time for a particle to be precipitated. Although it seems contrary to industrial practice, we obtain very little advantage from using long electrodes. Cottrell plants, which are working on solid as distinguished from liquid particulate matter, use collecting electrodes which are also conducting. When a run starts, the first precipitation occurs at the beginning of the electrodes, and if the precipitate is non-conducting it is possible that the maximum electrostatic field intensity

gradually travels up the tube so that there is an advantage in length. Our collecting electrode is made of glass, which is a poor conductor, and for this reason it may be unwarranted to draw comparisons between industrial plants and our apparatus on this particular point. In any event, for small scale work there is no doubt that the slight advantage gained by using long electrodes is much more than offset by the increased difficulty in handling the precipitate. It is best, therefore, to keep the electrodes as short as possible and to increase capacity by means of the primary rheostat.

b. The Diameter of the Collecting Electrode.—There is little choice in the diameter of the collecting electrode in electric precipitators having rectifying equipment and metallic electrodes. It is necessary to make it large enough to avoid sparking across the air gap. Tolman (13) and Bill (14) accomplished this by placing a rheostat in the primary circuit, and thus controlled the field intensity. Lamb (15) pointed out that there was little tendency to spark across the air gap in his small precipitator. Shibusawa and Niwa (16) confirmed this, but they used a kenotron in their small apparatus. Possibly Nesbit's formula for field intensities—the formula involving the logarithmic ratio of the radii of the electrodes—does not hold with our apparatus which may have somewhat the effect of a condenser as well as a rectifier. In any case, the diameter of the precipitator tubes can be made small, and this increases capacity. For example, we can obtain higher capacities at 15,000 volts with ¾-inch tubes and fine wire than with 2-inch tubes. This is not true of metal electrodes, however, since a ¾-inch tube is too small to prevent violent sparking. With a glass electrode and no other rectifier, a 2-inch diameter is too great. It is true that decreasing the diameter increases the air velocity, but the advantage of obtaining a more intense electric discharge apparently more than offsets the advantage of decreased air velocity. The optimum diameter of the tubes and the proper thickness of the glass are points upon which we still feel uncertain. The size shown in Figure 3A is the one which seems to be most satisfactory when celluloid foil is used. For collecting substances which are not to be photographed, tubes such as those shown in Figures 3B, C, and D, may be used.

c. Electrodes Connected in Parallel.—Capacities of industrial plants are increased by running a number of electrodes in parallel, both with regard to current and with regard to air flow. This is inadvisable for our work, however, as it gives more than one sample for a single determination. It is preferable to increase capacity by using higher field intensities and but one set of electrodes. In this connection, the data of Shibusawa and Niwa (16) are especially interesting. Their curves show that capacity (or efficiency) varies with both the secondary voltage and the amperage. It would seem, therefore, that doubling the number of electrodes should not double the capacity of a given installation but that the increased capacity should be somewhat less than double. Lamb found it possible to increase the capacity of his electric smoke mask by increasing the number of precipitator tubes. It should also be feasible to do the same thing in our apparatus, but for the reasons given we do not feel that it would be an advantage. For our work it is preferable to use but one tube, although we know of no reason why more could not be used.

d. The Effect Produced by Using Supple Electrodes.—Figure 4 shows a

curious form of precipitate which is obtained by using thick (⅛ inch) supple metallic precipitating electrodes and supporting them only at the upper or exhaust end of the tube. The lower part, where precipitation is heaviest, is, therefore, free to shake with the static discharges. While we have never been able to make two precipitations alike, the oval patterns at the upper end of the foil are usually plainly visible. We thought at first that they indicated the path followed by the free end of the precipitating electrode, but, as they are usually heaviest at the upper end where the shaking is less, this explanation is seemingly incorrect. Whether or not the precipitator is overloaded, as it was in this case, makes little difference. As a general rule these patterns are obtained only at the expense of low capacities, and are probably caused by the shaking of the electrode and consequent reduction in the effective diameter of the collecting electrode. By using the same ⅛-inch electrode fixed at both ends, substantially greater capacities are obtained than when one end of the electrode is loose.

V. Comparative Precipitating Capacities with Smoke, Fume, and Dust

It has already been pointed out that the appearance of the precipitate on the celluloid foil gives a delicate test of precipitation efficiency and, hence, of the capacity of the precipitator. Whether large or small precipitators are used and whether the light beam or foil method of detecting overloads is employed, the same sort of results are obtained. It is a simple matter to adjust the voltage, air speed, and concentration for smoke, fume, or dust, so that no material is visible in the light beam and none is precipitated above the aluminium foil on the outside of the collecting electrode. Then, by decreasing the voltage and increasing the air speed or concentration, material which is recognized first on the glass tube above the aluminium foil passes through. When the overload is increased slightly more, particles are recognized in the Tyndall box by the disappearance of the black line across the main beam from the carbon arc.

Figure 5 is a photograph of a silica precipitate, and shows a slight but perceptible overload which, in practical work, is probably too slight to be considered. The precipitator was running at 70 liters per minute. Figure 6 shows silica dust obtained with the precipitator running at 45 liters per minute—a little less than full capacity. Figure 7 shows ammonium chloride fume collected when the precipitator was obviously overloaded and the air flow was at 35 liters per minute. Figure 8 pictures ammonium chloride fume taken at as nearly full load as is possible. The air flow in this case was at 25 liters per minute. Tobacco smoke precipitates resulted in tarry droplets unsuited for photography. Furthermore, the particles were too small to be photographed by the equipment available (see Figure 11), and showed only the tarry droplets of condensed and precipitated moisture. Results with tobacco smoke showed that a safe load was 15 to 20 liters per minute as compared with 25 liters for ammonium chloride fume and about 50 liters for silica dust. The ease with which the precipitator could be overloaded with tobacco smoke was more pronounced than was the case with fume or dust. The same voltage and length of run were used in all three cases, while the concentration was kept as nearly the same in each pair of runs as was possible with the apparatus and methods used.

Similar photographs can be taken by using too low voltages or too high concentrations. It should be possible, therefore, to plot curves of precipitation efficiencies at various air speeds, concentrations, and field intensities (both secondary voltage and amperage being considered). The results obtained by Lamb (15) and by Shibusawa and Niwa (16) with ammonium chloride indicate that these relations are not linear and that it is probably economical to run industrial plants at a slight overload.

The results shown in our photographs indicate that, at a constant voltage, the precipitator has a capacity which varies with the number of particles passed through it, while the number, in turn, is governed by the size of the particles. Failure to appreciate the importance of these factors in overloading may be the reason why both Bill (14) and the Bureau of Mines (18) found the efficiency of their small Cottrell precipitators to be substantially less than 100 per cent. Tolman (13) and Lamb (15) used much lower rates of air flow and obtained complete precipitation. It is noticed that Warren and Read (23) accept 82.7 per cent. as Bill's figure for electric precipitation efficiency and use it in comparing the efficiency of several types of laboratory dust-collecting devices. In our opinion this is an injustice to Bill and to his method. He used solid aluminium tubes for most of his field work so that he was probably unable to examine the collected precipitate. In the face of a mass of industrial evidence that large particles, such as dust, and smaller particles, such as metallic oxide fumes, can be recovered at efficiencies close to 100 per cent., to say nothing of Lamb's and of Tolman's evidence of 100 per cent. recovery of fume and smoke with small precipitators, Warren and Read's acceptance of this low figure of 82.7 per cent. for silica dust seems unwarranted.

VI. The Adaptation of Electric Precipitation to the Photomicrography of Dust, Fume, and Smoke

The advantages of obtaining photomicrographs of dust, fume, and smoke particles as they occur in the air are obvious. Owens' (24) method for making such photographs is the only way that we have found which approaches quantitative accuracy. His method is limited to small samples (such as 50, 100, and 150 c.c., according to the condition of the air or gas being sampled). It seems to be best adapted to counting, although he has shown that it is well suited for photomicrographic work. Since there is but little choice in the amount of air sampled, there is equally little choice in the density of the field obtained on the cover slip. Owens has demonstrated the method to be accurate and particularly suited for taking samples when the gravimetric significance of the particles is slight. His apparatus, therefore, owing to its simplicity, compactness, light weight, sensitivity, and low cost, is excellent for taking small samples of particulate matter in air.

Figures 5, 6, 7, and 8 show the gradual tapering off of the precipitate obtained with the celluloid foil in our apparatus, and demonstrate that, by cutting a foil, a field of any desired intensity may be placed beneath the microscope. If the sample is handled with reasonable care the slight scratches which may be on either side of the celluloid are out of focus. Figures 9 and 10 are photographs of silica and ammonium chloride particles at a magnification of 680 diameters. The difference in the size of the particles is obvious. Tobacco smoke

FIG. 4.—Patterns made by using supple precipitating electrode.

FIG. 5.—Silica dust; precipitator overloaded. Rate 70 liters per minute.

FIG. 6.—Silica dust; complete recovery. Rate 45 liters per minute.

FIG. 7.—Ammonium chloride fume; precipitator overloaded. Rate 35 liters per minute.

FIG. 8.—Ammonium chloride fume; precipitator slightly overloaded. Rate 25 liters per minute.

particles could not be seen at this magnification, but there is no apparent reason why they could not be photographed with better equipment. Figure 11 is a photograph of droplets of water containing smoke particles. The magnification is 680 diameters and is obviously too low to show the smoke particles.

1. *The Dispersion of Particles Collected on Transparent Foils*

We have obtained no evidence to uphold the contention that high tension unidirectional current discharges produce true precipitation as distinguished from flocculation, nor is it admitted that the characteristics of the rectified current and voltage curves prove that such a current is necessary. It may doubtless be maintained that the precipitation produced by our apparatus, as distinguished from that produced by Cottrell precipitators which use current rectified by mechanical means or by thermionic valves, is due in some measure to flocculation. If this were true, it should be evident in both macroscopic and microscopic examinations of the precipitate collected on a transparent foil. There is no question that the silica and ammonium chloride particles shown in Figures 9 and 10 are dispersed and not flocculated. These were picked at random and can be duplicated with certainty. Since precipitation occurs at a rate which is practically instantaneous as compared with the much slower clearing up of smoke in a bottle when subjected to high tension alternating fields, it seems fairly certain that this method gives a true picture of the degree of dispersion of the particles in the air immediately before precipitation.

2. *Flocculation after Precipitation*

Landolt (25) states that the precipitate on the collecting electrodes of Cottrell precipitators has a flocculated as distinguished from a crusty or massive formation. If we run our apparatus with either ammonium chloride fume or dust for long enough periods to collect a heavy precipitate at the beginning of the celluloid foil, the precipitate always shows strong flocculation on the outer surface (the portion nearest the active electrode). If this flocculated material is carefully lifted off, the under portion usually has the normal, evenly dispersed appearance. All our results indicate that flocculation occurs after precipitation and is not produced until precipitation is dense enough to cause layers of particles to be built up. In other words, it is a surface effect similar to that produced when the terminals of an induction or Tesla coil are held on opposite sides of a glass slide covered with dust. This flocculation seems to offer no difficulties as far as photography is concerned, since it can always be avoided by making short runs or by selecting portions of the precipitate sufficiently removed from the flocculated region to give single layers and, therefore, dispersed fields. Furthermore, if photographs only are desired and no other examination of the collected precipitate is required, there is no need of running for more than a minute or two. After ten- to fifteen-minute runs the sample becomes too dense for photography unless the collection on the upper portion of the tube is used.

3. *The Size Distribution of Precipitated Particles*

We are not certain whether or not there is a tendency toward size distribution of the precipitate. Owing to their differences in mass and surface area it is natural to expect that the small and large particles would be precipitated at

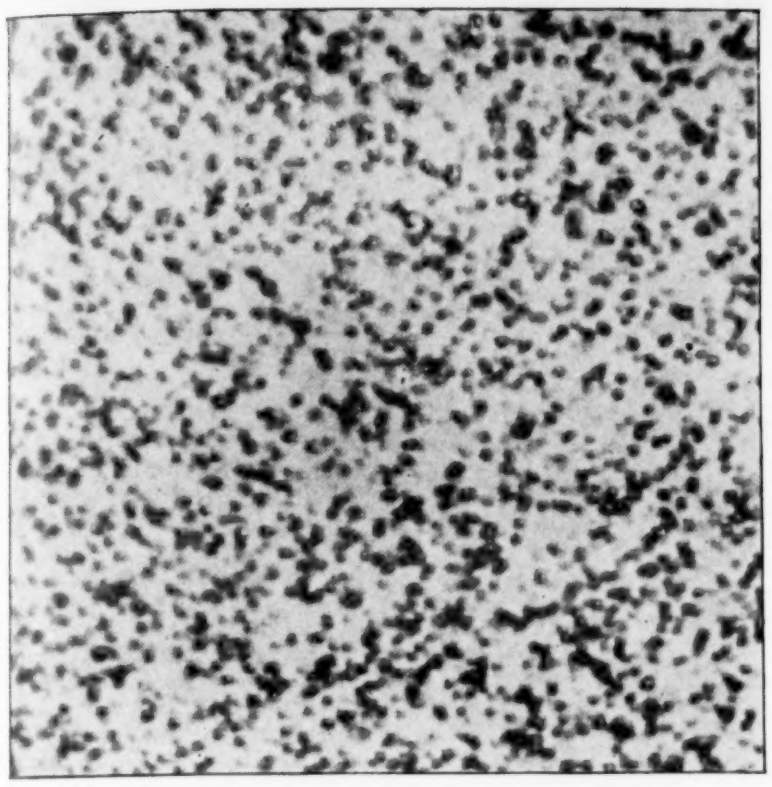

FIG. 9.—Silica dust particles. Average size 3 to 5 microns.

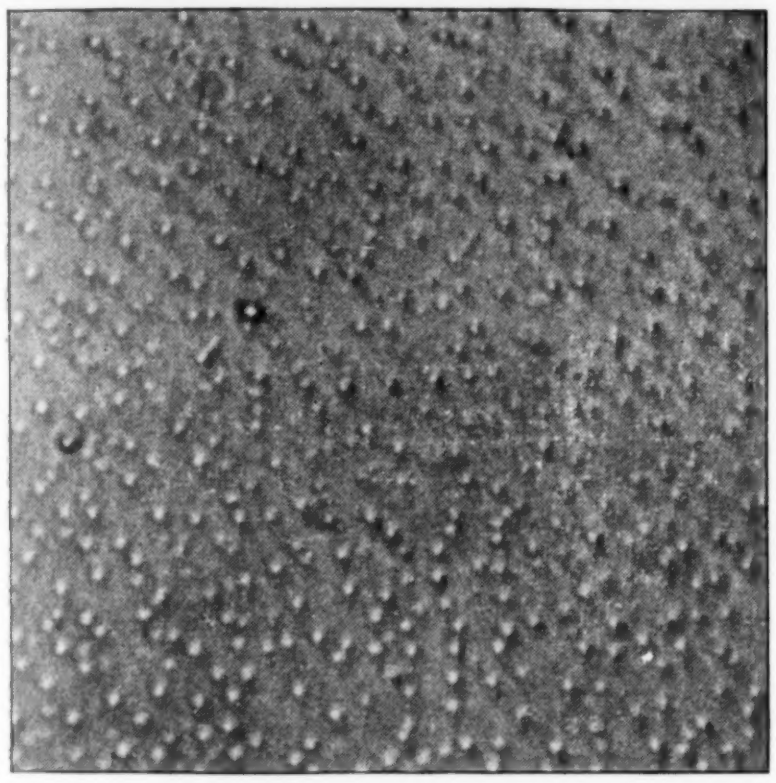

FIG. 10.—Ammonium chloride fume particles. Average size approximately 1 micron.

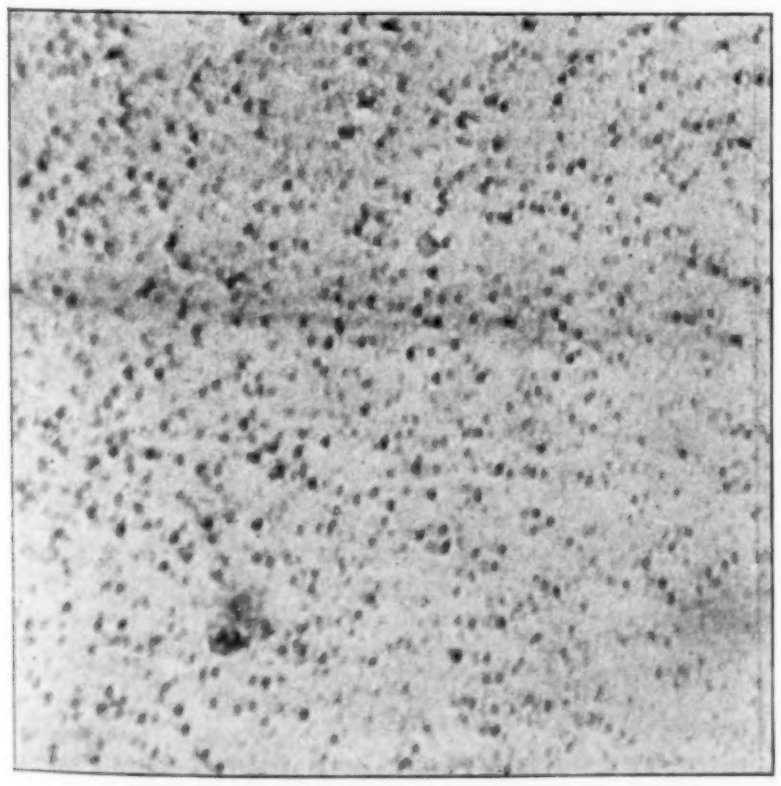

FIG. 11.—Droplets of tarry moisture from tobacco smoke precipitate. Magnification insufficient to show smoke particles.

different points, and that the large ones would be precipitated first. Figures 12 and 13 are photographs of sections of a silica precipitate cut from the same foil, and are typical of runs made at considerable overload in order to draw out the area of precipitation. The heavier pre-

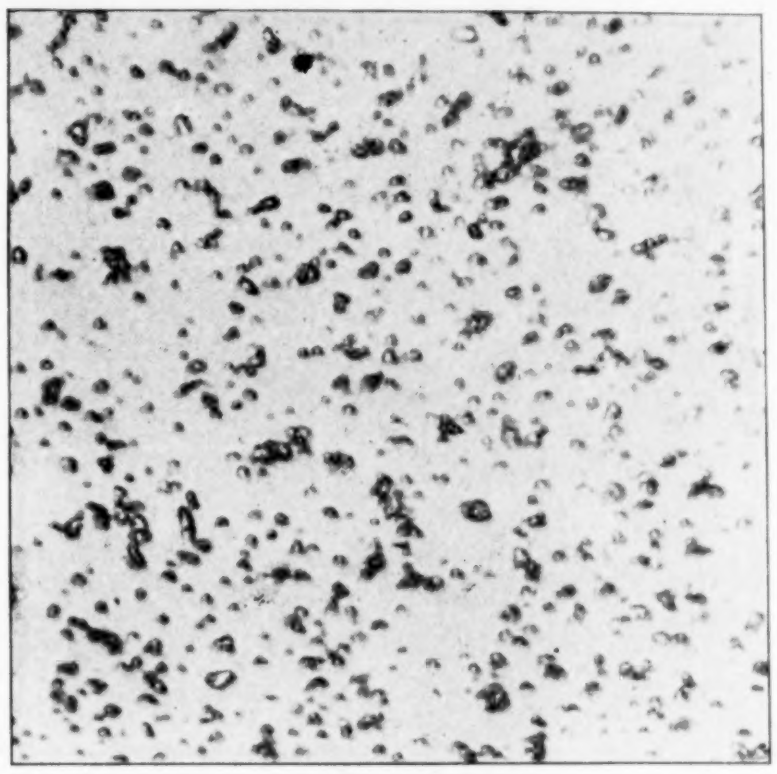

FIG. 12.—Silica particles from lower portion of foil. Magnification 680 diameters.

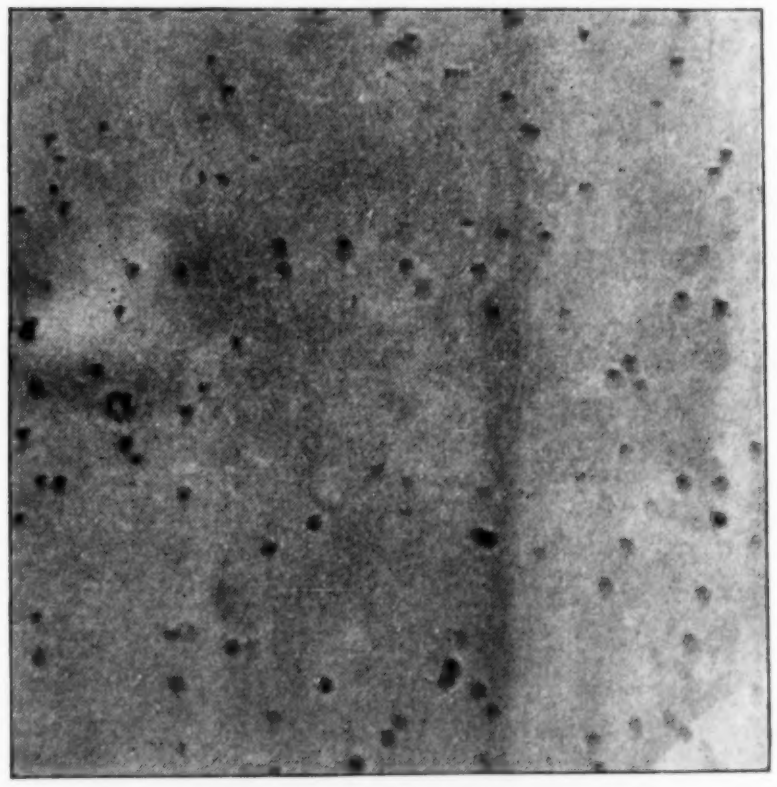

FIG. 13.—Silica particles from upper portion of foil. Same sample as shown in Figure 12.

cipitation of Figure 12 indicates that this section was taken from the lower end of the precipitating electrode, while Figure 13 shows a section from the upper end.

The fact that electric precipitators are

ineffective against gases as distinguished from particulate matter, supports our evidence on the important effect that particle size exerts on precipitation. The smaller the particles and the more nearly they approach a true gas, the more difficult it should be to effect their precipitation.

It was thought that particles nearer the wire might be subjected to more intense precipitation than those near the glass electrode. We therefore made up a special apparatus consisting of one glass tube inside another. The cross-sectional areas of the inner tube and of the annular portion of the outer tube were made approximately equal. Both tubes were fitted tightly to the precipitator. A black dust was floated through the inner tube and a white dust through the outer tube, both dust streams passing through at approximately equal rates and concentrations. The precipitate collected on the foil showed no positive evidence of selective precipitation of either dust at any place on the foil.

4. *A Qualitative Electric Precipitator for Photomicrographic Sampling*

A device for photomicrographic sampling which has been developed in this laboratory is shown in Figure 14. It requires no electric equipment other than a storage battery, such as the standard lead sulphuric acid type used in automobiles, and a cheap automobile induction coil. Owing to the construction of the coils there is a right and a wrong way of connecting the terminals to the precipitator slide. This may be determined by holding the terminals near a metal pipe or some other convenient ground and noticing from which terminal the spark jumps the greatest distance. The best results are obtained by connecting the more powerful terminal to the wire. In using the device it is advisable to turn it upside-down, as shown, or on its side. In this way no particles settle out on the plate by gravity. It is also advisable to include a dummy or blank slide in the holder in order to make certain that precipitation takes place as desired. In atmospheres such as those in dusty factories we have found this apparatus

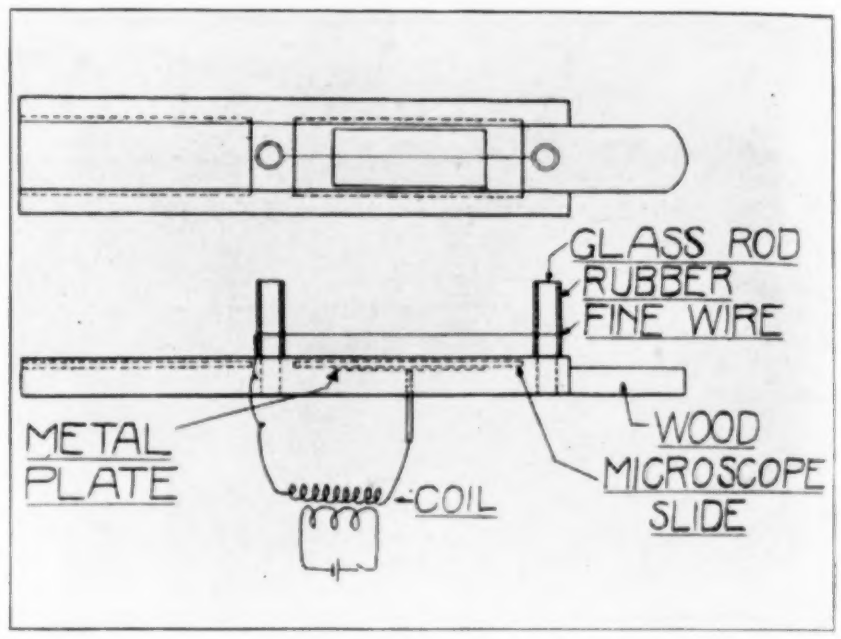

FIG. 14.—Qualitative microscopic sampler.

useful, since its essentials can be assembled at the plant by simply removing a battery and induction coil from the automobile in which the rest of the apparatus has been transported. At best it has a very low capacity, and the field is not sufficiently intense to catch particles which move by at appreciable velocities. It seems to give fairly representative samples but the low intensity of the electric field makes the precipitation of fine particles, if they occur in any considerable numbers, uncertain. Figure 15 shows a sample of talc dust taken by Dr. F. G. Pedley, who assisted in this work, in a factory where this material was used in the manufacture of rubberized copper cables. This qualitative precipitator could doubtless be improved but the higher capacity precipitators accomplish everything that the small one strives for, so that little time has been devoted to its development.

VII. Electric Shocks and Surface Leakage

It is probably unnecessary to discuss this point as any one using even the storage battery apparatus will, after one or two experiences at least, avoid receiving shocks. If reasonable precautions, as dictated by common sense, are observed, and if particular care is taken not to handle the precipitators unless the current is off, there is no danger in using this type of apparatus at voltages as high as 25,000. Unless the high tension leads are heavily insulated, however, there is sufficient leakage in the vicinity of the wires to give one an unpleasant shock without his having actually touched the wire or caused a disruptive spark to jump the gap. The same effect can be shown by holding a smoking match or cigarette near the brush discharge from a high voltage coil. The discharge will follow down the smoke stream and on through the earth. It is unnecessary actually to touch the terminal or to cause a disruptive spark to jump the intervening air gap.

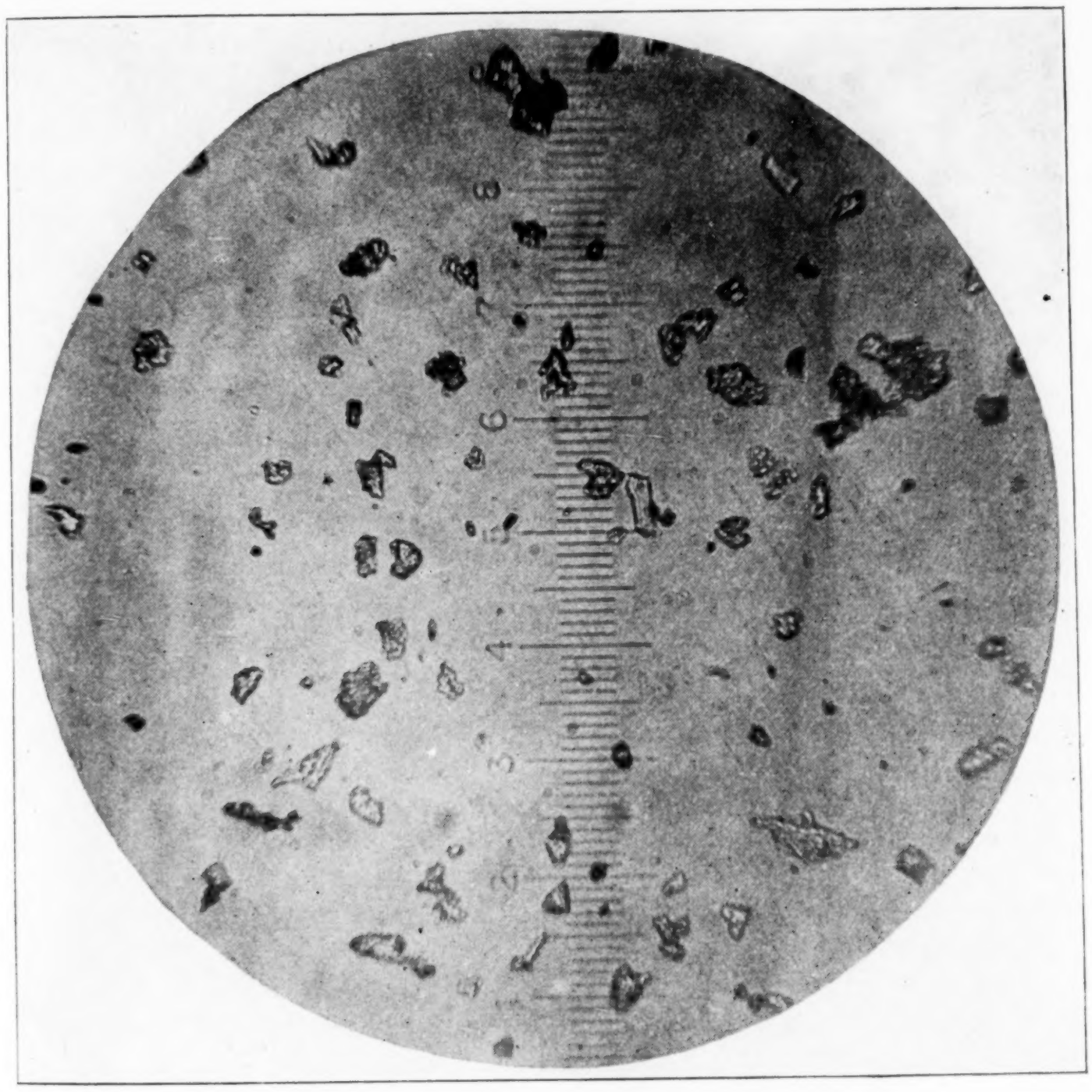

Fig. 15.—Talc dust sampled by qualitative precipitator. x 400 (approx.). Average size 9 to 10 microns. One large scale division=32 microns.

In wet weather there is the same tendency for surface leakage to lower the effective voltage at the discharge terminals of our apparatus as is experienced with any high tension electrostatic apparatus. Consequently, it is best to

insulate heavily the high tension sides; otherwise, the intensity of the corona field is reduced and with it the capacity of the precipitator. Insulated wires such as are used in standard X-ray outfits should suffice. Without such insulation the actual electrical efficiency of the apparatus, in terms of wattage input and output, is probably very low.

VIII. Summary

The theory of high tension electric precipitation is discussed with a view particularly to the construction and operation of small precipitators for the quantitative determination of smokes, fumes, and dusts in air. The flocculating and precipitating actions of alternating and unidirectional currents are compared, and a precipitator involving neither mechanical nor valve rectifiers is described in detail.

The ease with which electric precipitators can be overloaded and, at the same time, work at less than maximum efficiency is pointed out, and is shown to vary markedly with the size and number of particles passing through the electrostatic field. It is shown that the distribution of the precipitate offers a convenient and simple field test for overloading.

Quantitative precipitation, as indicated by the Tyndall light beam test and by the distribution of the precipitate on the electrode, can be obtained by using a Pyrex glass collecting electrode and a fine wire or stiff rod for the precipitating electrode. Lining the tube with a thin transparent foil, such as celluloid, which may be readily withdrawn after a run, makes it possible to take photographs of the precipitated matter. All the evidence obtained indicates that true precipitation and not flocculation occurs, and that complete rectification in small scale apparatus is unnecessary.

Bibliography

1. Drinker, P., Thomson, R. M., and Fitchet, S. M.: Atmospheric Particulate Matter: I. Dust, with a New Apparatus for its Determination. This Jour., 1923-1924, *5*, 19, 62.
2. Gibbs, W. E.: The Industrial Treatment of Fumes and Dusty Gases. Jour. Soc. Chem. Indust., 1922, *41*, 189T.
3. Lodge, O.: Historical Note on Dust, Electrification, and Heat. Nature, 1904-1905, *71*, 582.
4. Lodge, O.: The Electric Disposition of Dust, Smoke, etc. Jour. Soc. Chem. Indust., 1886, *5*, 572.
5. Cottrell, F. G.: The Electrical Precipitation of Suspended Particles. Jour. Indust. and Engin. Chem., 1911, *3*, 542.
   Cottrell, F. G.: Problems in Smoke, Fume, and Dust Abatement. Smithsonian Ann. Report, 1913, 653.
6. Cottrell, F. G.: Recent Progress in Electrical Smoke Precipitation. Engin. Min. Jour., 1916, *101*, 385.
   Bush, H. J.: Electrical Precipitation. Jour. Soc. Chem. Indust., 1922, *41*, 22T.
7. Nesbit, A. F.: The Theoretical and Experimental Consideration of Electrical Precipitation. Proc. Am. Inst. Elec. Eng., 1915, *34-2*, 507; Tr. Am. Inst. Elec. Eng., 1915, *34 Part 1*, 405.
8. Tolman, R. C., and Karrer, S.: Motion of Droplets and Particles in the Field of the Corona Discharge. Chem. Met. Eng., 1920, *22*, 1203.
9. Strong, W. W.: Electrical Precipitation. Theory of the Removal of Suspended Matter from Fluids. Proc. Am. Inst. Elec. Eng., 1915, *34-2*, 229; Tr. Am. Inst. Elec. Eng., 1915, *34 Part 1*, 397.
10. Saget: La Précipitation électrique des poussières. Rev. mét., 1922, *19*, 703.
11. Winne, H. A.: The Cottrell Process of Electrical Precipitation. General Electric Rev., 1921, *24*, 910.
12. Dushman, S.: A New Device for Rectifying High Tension Alternating Currents. The Kenotron. *Ibid.*, 1915, *18*, 156.
13. Tolman, R. C., Reyerson, L. H., Brooks, A. P., and Smyth, H. D.: An Electrical Precipitator for Analyzing Smokes. Jour. Am. Chem. Soc., 1919, *41*, 587.

14. Bill, J. P.: The Electrostatic Method of Dust Collection as Applied to the Sanitary Analysis of Air. THIS JOUR., 1919-1920, *1*, 323.

15. Lamb, A. B., Wendt, G. L., and Wilson, R. E.: A Portable Electric Filter for Smokes and Bacteria. Tr. Am. Electrochem. Soc., 1919, *35*, 357. See also Lamb, A. B.: U. S. Patent 1,442,619 (Jan. 16, 1923).

16. Shibusawa, M., and Niwa, Y.: A New Electrical Precipitation Treater. Jour. Am. Inst. Elec. Eng., 1920, *39*, 890.

17. Tolman, R. C., Vliet, E. B., Peirce, W. McG., and Dougherty, R. H.: The Disappearance of Smoke in a Confined Space. Jour. Am. Chem. Soc., 1919, *41*, 304.
See also
Whytlaw-Gray, R., Speakman, J. B., and Campbell, J. H. P.: Smokes: Part I.—A Study of their Behaviour and a Method of Determining the Number of Particles they Contain. Proc. Roy. Soc., London, 1923, Series A, *102*, 600.
Whytlaw-Gray, R., and Speakman, J. B.: Smokes: Part II.—A Method of Determining the Size of the Particles in Smokes. *Ibid.*, p. 615.

18. Katz, S. H., Longfellow, E. S., and Fieldner, A. C.: Efficiency of the Palmer Apparatus for Determining Dust in Air. THIS JOUR., 1920-1921, *2*, 167.
See also
Fieldner, A. C., Katz, S. H., and Longfellow, E. S.: The Sugar-Tube Method of Determining Rock Dust in Air. U. S. Bur. Mines, 1921, Tech. Paper 278.

19. Wells, P. V., and Gerke, R. H.: An Oscillation Method for Measuring the Size of Ultramicroscopic Particles. Jour. Am. Chem. Soc., 1919, *41*, 312.

20. Rothmund, V.: Ueber das Auftreten von Nebeln bei chemischen Reaktionen. Monatsh. f. Chem., 1918, *39*, 571 (see p. 596).

21. Fieldner, A. C., Oberfell, G. G., Teague, M. C., and Lawrence, J. N.: Methods of Testing Gas Masks and Absorbents. Jour. Indust. and Engin. Chem., 1919, *11*, 519.

22. Oberfell, G. G., and Mase, R. P.: An Automatic Compensating Flow Meter. *Ibid.*, p. 294.

23. Warren, P. H., and Read, T. A.: Methods and Apparatus for Dust Suspended in Air. Proc. Australian Inst. Min. and Met., 1922, N. S. No. 47, 297.

24. Owens, J. S.: Jet Dust Counting Apparatus. THIS JOUR., 1922-1923, *4*, 522.

25. Landolt, P. E.: Cottrell Process. Tr. Am. Electrochem. Soc., 1914, *26*, 255.

BOOKS RECEIVED

Books received are acknowledged in this column, and such acknowledgment must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interest of our readers and as space permits.

La Céruse: Une Grave Question d'Hygiène Professionnelle et Sociale. By *F. L. Cantineau*, Ingénieur A.I.Lg., Capitaine-Commandant du Génie, de réserve, Directeur-Général au Ministère des Affaires Économiques de Belgique. Paper. Pp. 480. Paris and Liége: Ch. Béranger, 1921.

Environment and Resistance in Tuberculosis. By *Allen K. Krause*, A.M., M.D., Associate Professor of Medicine, Johns Hopkins University; Director, Dows Tuberculosis Research Fund, Johns Hopkins University; Physician in Charge, Phipps Tuberculosis Dispensary, Johns Hopkins Hospital; Lecturer, Trudeau School of Tuberculosis; Editor, American Review of Tuberculosis; Author of a Section on Tuberculosis in Nelson's Loose Leaf System of Medicine, and of the Section on Tuberculosis in the United States for the Encyclopedia Britannica. Cloth. Pp. 137. Baltimore: Williams & Wilkins Company, 1923.

Rest and Other Things. By *Allen K. Krause*, A.M., M.D., Associate Professor of Medicine, Johns Hopkins University; Director, Dows Tuberculosis Research Fund, Johns Hopkins University; Physician in Charge, Phipps Tuberculosis Dispensary, Johns Hopkins Hospital; Lecturer, Trudeau School of Tuberculosis; Editor, American Review of Tuberculosis; Author of a Section on Tuberculosis in Nelson's Loose Leaf System of Medicine, and of the Section on Tuberculosis in the United States for the Encyclopedia Britannica. Cloth. Pp. 159. Baltimore: Williams & Wilkins Company, 1923.

Eighth Annual Meeting of

THE AMERICAN ASSOCIATION OF INDUSTRIAL PHYSICIANS AND SURGEONS

Buffalo, N. Y., October 1, 2 and 3

Program

Monday, October 1—10 A. M.
Statler Hotel, Buffalo, N. Y.

BUSINESS MEETING

1. Remarks by the President.
2. Report of Secretary-Treasurer.
3. Reports of Committees.
4. Appointment of Nominating Committee.

Monday, October 1—2 P. M.
Statler Hotel

Joint Session of the Association and the National Safety Council. There will be three speakers, two from the Safety Council and one from the Association.

Tuesday, October 2—10 A. M.
Statler Hotel

Joint Session of the Association and the Health Service Section of the National Safety Council.

1. SOME EXPERIENCE IN THE COLLECTION OF INDUSTRIAL MORBIDITY STATISTICS FROM VARIOUS SOURCES. *L. R. Thompson, M.D., U.S.P.H.S.*, Washington, D. C., and *Dean K. Brundage, U.S.P.H.S.*, Washington, D. C.
2. SOME OF THE NEWER INDUSTRIAL POISONS. *Alice Hamilton, M.D.*, Boston, Mass.
3. SURGERY OF THE SPINE. *Russell Hibbs, M.D.*, New York City.
4. THE PREVENTION, REHABILITATION, AND MEDICOLEGAL ASPECTS OF SPRAINED BACK. *John N. Bassin, M.D.*, Newark, N. J.

Tuesday, October 2—2 P. M.
Statler Hotel

Joint Session of the Association and the Safety Council.

1. Annual address of the President. *C. E. Ford, M.D.*, New York City.
2. HEAT HAZARDS IN INDUSTRY. *G. H. McKinistry, M.D.*, Pittsburgh, Pa.
3. RELATION OF THE INDUSTRIAL SURGEON TO THE FAMILY PHYSICIAN. *Harold G. Giddings, M.D.*, Boston, Mass.
4. RELATION OF INDUSTRIAL MEDICINE TO GENERAL PRACTICE. *Harry Meyers, M.D.*, Mansfield, Ohio.
5. SHOULD THE PHYSICIAN GO OUT INTO THE PLANT? *Wade Wright, M.D.*, Boston, Mass.

Wednesday, October 3—10 A. M.
Municipal Hospital

Joint Session of the Association and the Health Service Section, National Safety Council.

1. THE ECONOMIC VIEWPOINT UPON SYPHILIS IN INDUSTRY. *W. Louis Hartman, M.D.*, Detroit, Mich.
2. THE PHYSICAL EXAMINATION OF 50,000 GARMENT WORKERS. *George M. Price, M.D.*, New York City.
3. THE ENDICOTT JOHNSON MEDICAL SERVICE. *Daniel C. O'Neil, M.D.*, Binghamton, N. Y.
4. FURTHER STUDIES IN MENTAL HYGIENE IN INDUSTRY. *Frederick W. Dershimer, M.D.*, Cleveland, Ohio.

Wednesday, October 3—1 P. M.

Luncheon at the Municipal Hospital, followed by a study of the Hospital's rehabilitation service and facilities.

Fifty-Second Annual Meeting of THE AMERICAN PUBLIC HEALTH ASSOCIATION Boston, Mass. October 8-11, 1923

Tentative Program

INDUSTRIAL HYGIENE SECTION

SESSION I *

Reading of Minutes of Previous Meeting.

Election of Nominating Committee.

Address of Chairman.

THE STATUS OF THE PROBLEM OF RESUSCITATION IN CASES OF RESPIRATORY FAILURE. *Cecil K. Drinker, M.D.*, Laboratory of Applied Physiology, Harvard Medical School, Boston, Mass.

STANDARDS FOR PROCEDURES IN LEAD POISONING. *Joseph C. Aub, M.D.*, Laboratory of Applied Physiology, Harvard Medical School, Boston, Mass.

Discussion led by Dr. Fairhall, Harvard Medical School, and Miss Minot, Harvard Medical School.

THE DISEASES OF PRESSERS AND TAILORS, BASED ON SUPERVISION OF SIX THOUSAND WORKERS FOR TEN YEARS. *George M. Price, M.D.*, Director of Union Health Center, New York City.

Discussion led by J. W. Schereschewsky, M.D.

PHYSIOLOGICAL STUDIES IN CONNECTION WITH VENTILATION. *Philip Drinker, B.S., Ch.E.*, School of Public Health, Harvard University, Boston, Mass.

THE USE OF ELECTRIC PRECIPITATION IN THE ESTIMATION AND MICROSCOPIC STUDY OF ATMOSPHERIC DUST, FUMES, AND SMOKE. *Philip Drinker, B.S., Ch.E.*, School of Public Health, Harvard University, Boston, Mass.

Discussion led by Mr. Leonard Greenburg, U. S. Public Health Service, New Haven, Conn.

*This session will probably be held in the School of Public Health of Harvard University, on account of the two demonstrations by Mr. Drinker.

SESSION II

Business Meeting, Industrial Hygiene Section.

THE DIAGNOSTIC CLINIC OF THE HENRY PHIPPS INSTITUTE, WITH ANALYSIS OF CASES. *Frank A. Craig, M.D.*, Henry Phipps Institute, Philadelphia, Pa. (Tentative.)

STANDARDS OF TEN THOUSAND PHYSICAL EXAMINATIONS OF INDUSTRIAL WORKERS. *L. R. Thompson, M.D.*, Surgeon in Charge, Industrial Hygiene Bureau, U. S. Public Health Service, Washington, D. C.

Report of Nominating Committee.

Election of Section Officers.

OCCUPATIONAL DISEASE COMPENSATION. *John B. Andrews, Ph.D.*, Secretary, American Association for Labor Legislation, New York City.

Discussion led by F. L. Rector, M.D., Secretary, Conference Board of Physicians in Industry, Boston, Mass.; and E. R. Hayhurst, M.D., Ph.D., Professor of Hygiene, Ohio State University; Consultant, State Department of Health, Columbus, Ohio.

THE ECONOMICS OF INDUSTRIAL HEALTH SERVICES. *Bernard L. Wyatt, M.D.*, Director Health Service, Laurentide Co., Grand'mere, Quebec.

It is also probable that a speaker of international reputation in this field will be secured to speak at one of the General Sessions on the subject of "The Economics of Industrial Hygiene," having in mind the shortage of labor at the present period, the restrictions on immigration, etc.

Emery R. Hayhurst, M.D.
Chairman, Program Committee

J. I. H.
Sept., 1923